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Noise Control

Proceedings: Bureau of Mines Technology Transfer Seminar, Pittsburgh, Pa., January 22, 1975

UNITED STATES DEPARTMENT OF THE INTERIOR

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Compiled by Staff–Mining Research
Bureau of Mines, Pittsburgh, Pa.

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NOISE CONTROL

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Staff–Mining Research, Bureau of Mines, Pittsburgh, Pa.

ABSTRACT

Research workers from the Bureau of Mines and industry met with other government and industry representatives in Pittsburgh, Pa., on January 22, 1975, to discuss the results of research under the Bureau of Mines Noise Control Program. The program, aimed at reducing noise in mines, is functionally divided into three major areas: Instrumentation, personal protection, and noise abatement. This proceedings contains the opening remarks to the seminar and seven technical presentations based on various aspects of noise abatement and control.

INTRODUCTION[1]

The following papers describe some of the more mature aspects of the Bureau of Mines Noise Control Program; the program is functionally divided into three major areas: Instrumentation, personal protection, and noise abatement.

Briefly, the Bureau work in instrumentation has been directed toward the development and evaluation of audio dosimeters to determine a miner's full-shift noise exposure without the need (and some times the hazard) of another individual being present. Both personal audio dosimeters and time resolved dosimeters have been developed. The personal audio dosimeter provides, at the end of the shift, a quantitative indication of the worker's total exposure; the time resolved dosimeter gives a times history of the worker's exposure during the shift.

In the personal protection area, emphasis has been directed toward the resolution of the potential hazards to the miner of wearing ear protection and not being able to hear warning signals such as roof talk. A discriminating earmuff has been developed and evaluated that provides protection at high levels but in the absence of high level background noise permits the miner to detect lower level signals while wearing the earmuffs.

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[1]By John N. Murphy, research supervisor, Federal Bureau of Mines, Pittsburgh Mining and Safety Research Center, Industrial Hazards and Communications, Pittsburgh, Pa.

Concerning noise abatement and control, efforts have proceeded in three general areas: Pneumatic stopers, mining machinery, and coal preparation plants. Notable progress has been made in identifying noise sources and introducing alternate components or developing noise control measures. Although more work remains to be done, progress has been made that can be used by the industry.

The Bureau's noise program is being conducted with in-house projects and via contract research; hence, we have Bureau personnel- and contractor-authored papers. This program has been implemented to date through extensive fieldwork, which has been possible only through the cooperation and participation of the mine operators and equipment manufacturers to whom we are indebted.

ACKNOWLEDGMENTS

The Office of the Assistant Director--Mining and the Technology Transfer Group wish to express their appreciation to the speakers and the many people who helped with the seminar. Special credit is extended to Kenneth Sacks, Pittsburgh Mining and Safety Research Center, for his efforts in compiling these proceedings. Appreciation is also extended to John N. Murphy, research supervisor, Industrial Hazards and Communications, Pittsburgh Mining and Safety Research Center, for planning and implementing this seminar, and to Norman Hanna, Pittsburgh Mining and Safety Research Center, for his aid in making the arrangements to accommodate seminar attendees. Throughout these proceedings, mention of trade names is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

OPENING REMARKS

by

Joseph J. Yancik[1]

It is gratifying to see so many of you here today showing an interest in the Bureau of Mines Noise Research Program, but at the same time it is just a little bit frightening because noise must be a very serious problem. Now I say "must be" because in our Coal Mine Health and Safety Research Program we have been working at this problem of noise since its inception, and as each year goes on, the problem seems to multiply. Noise is everybody's problem because it's a problem that exists everywhere.

In the mining industry, we are faced with difficult noise problems, and we have quite a program for you today to talk about this problem. I think it's safe to say that we are far from finding solutions to some of these problems. Progress has been made in some areas of noise control and abatement, and you will hear about these today. I think it is quite evident by your attendance here and the questions that are being asked that we have a lot more work to do and not just the Bureau of Mines but all of us, all of you industry people. We need your help more than ever and perhaps we can provide some help to you. If this seminar will provide an open forum for information exchange and honest dialogue between those that have the problems and hopefully those that have the solutions, then we have accomplished what we have set out to do. I am not a technical expert in noise so I am going to keep my remarks very brief. I would like to give you a very quick bird's-eye view of our Technology Transfer Program and its relationship to our total program.

We have in our Mining Research Program three basic areas. The Health and Safety Program, the Environmental Program, and the Advancing Mining Technology Program. In the Advancing Mining Technology Program, our orientation is primarily toward improving the technology of the extraction process, or the actual winning of the coal or ore while maintaining safety. Research conducted under the Health and Safety Program is aimed at improving the working environment for the miner, while the Environmental Program pursues avenues for extracting coal and ores at acceptable costs to the environment. We conduct research in these three programs through an in-house research program at four Bureau Research Centers located in Pittsburgh, Pa., Denver, Colo., Spokane, Wash., and Minneapolis, Minn., and also through a contract program much of which is done through competitive procurements with mining companies and related industries. The actual transfer of research results can assume many different forms, and this seminar is just one. And of course, research accomplishments must go to the industry because the Bureau of Mines does not mine any coal or any other mineral. You are the people that must use this technology so we have to find out what it is you need, want, and can use, do

[1]Assistant director--Mining, U.S. Department of the Interior, Bureau of Mines, Washington, D.C.

the research, transfer the results, and then get feedback from you. Today we are here to transfer some recent results from our noise research and to get your response.

We have a rather substantial budget and it would take me quite a little while to cover it in detail. Under the Coal Mining Health and Safety Research Program, approximately $27.6 million is available this year (fiscal year 1975); of this amount, roughly $980,000 dollars is being allocated to noise research by the Bureau.

Since the inception of the Coal Mine Health and Safety Program in fiscal year 1970, as a result of the passage of the Federal Coal Mine Health and Safety Act of 1969, approximately $130 million have been appropriated by Congress for coal mining health and safety research. In the fiscal year 1976 budget, which is just now being sent to Congress, we have a total Coal Mine Health and Safety Program of approximately $29 million.

I think that the administration, the Bureau of Mines, and industry recognizes the need and the value of this program and continues to support it. I would like to spend just a few minutes talking about some of the other parts of our program.

If you are interested in an area of research that is part of our program--or even if it is not a part of our program--I would urge you to communicate that interest to us. You have an ideal opportunity today by filling out the questionnaire sheet that is included in your information package. There are a great many publications that are available that I think you will find very useful. My time is up, so I will turn the microphone over to the experts because they have something to tell you.

Thank you for coming, I hope this is both a probitable and enjoyable seminar for you.

NOISE ABATEMENT IN MINING MACHINERY

by

Charles R. Summers[1]

ABSTRACT

A contract by the Bureau of Mines with Apt, Bramer, Conrad and Associates, Inc., was completed to define the noise sources and to assess the in-mine corrective measures to reduce operating noise levels and to experimentally evaluate the effectiveness of the measures to a roof bolter, a continuous miner, and rotary roof bolter. The roof bolter was successfully quieted by the installation of a suitable muffler. The miner was found to exhibit major noise sources similar to the loader except for the head of the miner; therefore, it was decided to concentrate work on the loader because it was the simpler of the two and employed the same type of conveyor that was found to be the major noise source.

This paper describes the methods of attenuating the noise sources of the conveyor of a Joy 14BU-10 loader that reduced the total, in-mine noise at the operator's position from 101 dbA to 94 dbA. This reduction increases the duration of operation from about 1-3/4 hours to about 4-1/2 hours per 8-hour shift. Since the average operating time of a loader is about 3 hours per 8-hour shift, this reduction puts the operator in compliance with existing noise standards.

INTRODUCTION

In compliance with the Coal Mine Health and Safety Act of 1969, Public Law 91-173, a mandatory noise standard[2] was adopted.

To assess the nature of the noise problems in underground coal mines, surveys have been conducted to determine the extent of the problem and the principal noise sources. A 21-mine survey as shown in table 1[3] identifies the principal problem areas as the pneumatic drill roof bolting operator, continuous miner operators, and the loading machine operators. The concern of this work is directed toward continuous miners, loading machines, and rotary roof bolters.

---

[1]Research physicist, U.S. Department of Interior, Bureau of Mines, Pittsburgh Mining and Safety Research Center, Industrial Hazards and Communications, Bruceton, Pa.

[2]U.S. Code of Federal Regulations. Title 30--Mineral Resources; Chapter 1--Bureau of Mines Department of the Interior; Subchapter O--Coal Mine Health and Safety; Part 70--Mandatory Health Standards, Underground Coal Mines; Subpart F, Noise Standards. Federal Register, v. 36, No. 130, July 7, 1971, pp. 12739-12741.

[3]Lamonica, J. A., R. L. Mundell, and T. L. Muldoon. Noise in Underground Coal Mines. BuMines RI 7550, 1971, p. 9.

TABLE 1. - Sound level averages and ranges for the occupations studied during the Bureau's 21-mine environmental noise survey

Occupation	Number sampled	Operation	Sound level, dbA	
			Mean[1]	Range
Man trip..................	-	Man trip...........	93	74-100
Pneumatic roof bolter......	9	1 drill, drilling...	112	104-118
		2 drills, drilling..	112	107-118
		Tighten bolt........	103	93-105
		Air on only.........	84	77-94
Loading machine operator...	8	Load................	99	90-108
		Maneuver............	93	85-97
		Tram................	90	90-98
Continuous miner operator..	17	Cut and load........	97	89-107
		Maneuver............	89	83-92
		Tram................	88	82-92
Rotary roof bolter.........	12	2 drills, drilling..	97	92-101
		1 drill, drilling...	95	85-106
		Tram................	87	80-91
		Idle................	87	84-96
Cutting machine operator...	5	Sump................	96	93-98
		Shear...............	94	85-103
		Undercut............	92	85-99
		Tram................	86	80-94
Coal drill operator........	3	Drill...............	94	80-104
Shuttle car operator.......	8	Loading.............	93	90-98
		Dumping.............	88	84-94
		Tramming............	87	85-92

[1]"Mean" is the mean of the samples and not the mean of the range.

NOISE SOURCES OF THE LOADER

Tramming the loader is not a noise problem. This source is below 90 dbA. When the gathering arms and the conveyor are in operation, the noise level exceeds 100 dbA; the conveyor is the major source of noise. The specific sources of the conveyor were found to be the following:

1. Impact and friction of the tail roller and its tension springs.

2. Chain and flights bounce along the top and return deck especially at points of direction change.

3. Impact of the flights and coal along the sides of the top deck.


FIGURE 1. - Tail end and roller of a Joy 14-BU10 loader.

Modification 1

Considerable noise is generated at the tail roller. At this position, shown in figure 1, the mechanical chain and its flight makes a 180° change in direction; that is, from travel along the top deck to travel along the return deck of the conveyor. The impacts of the chain with the roller are transferred to the machine body, which comprises large steel areas; such areas are perfect noise radiators. The noise control for this source is isolation of the tail roller from the machine body. Figures 2-3 show the roller mounted on guide rods that fit through a hole in the roller axle. Isolation is accomplished by reducing the diameter of the guide rod to permit insertion in a cylindrical bushing comprised of three concentric cylinders; the inner and outer cylinders were made of steel, and the in-between cylinder was made of energy-absorbing material. A steel angle was welded to the axle to keep the bushing in place. To isolate the roller from the tension spring, a thick washer of energy-absorbing material was installed between two metal spring pressure washers. This completely isolates the tail roller from the main frame of the loader.

Modification 2

In the original design, the plane of the top deck was not tangent to the periphery of the tail roller where the chain approaches the roller. This created a point of impact and consequently a noise source. To correct this malfunction, a steel ramp, a few inches wider than the chain, was welded to the top deck as shown in figure 4.

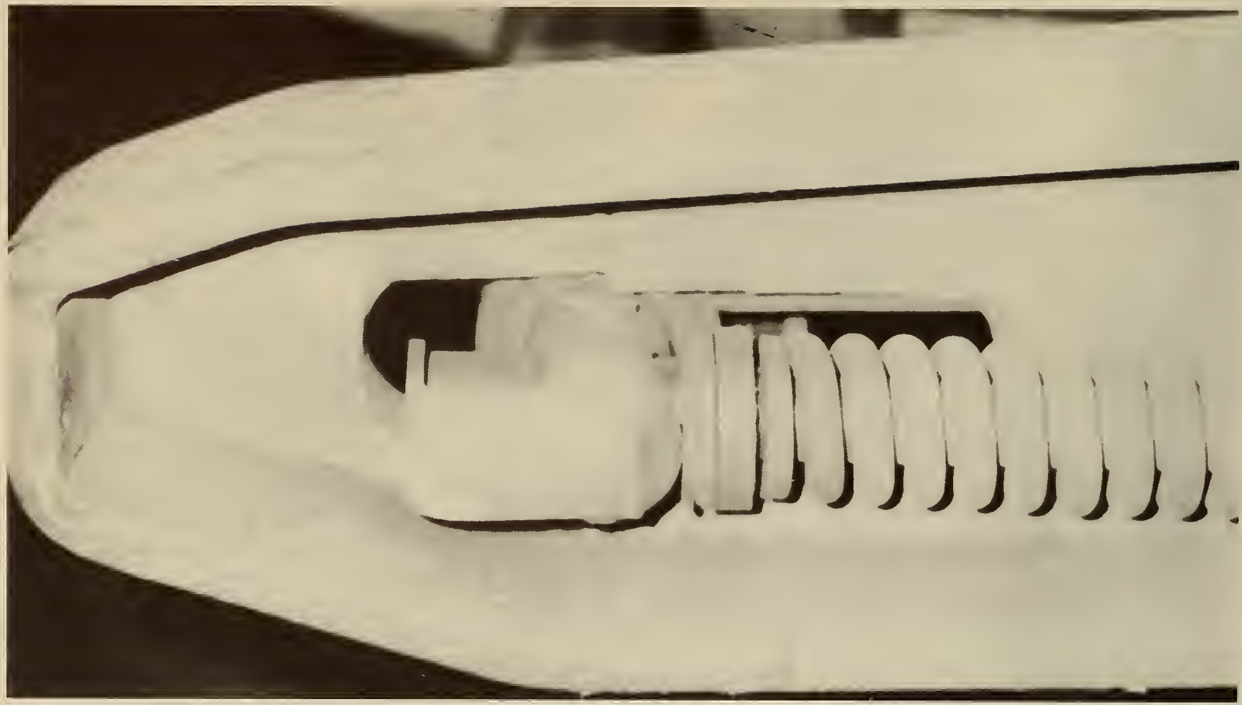

FIGURE 2. - End view of tail roller and isolated mountings.

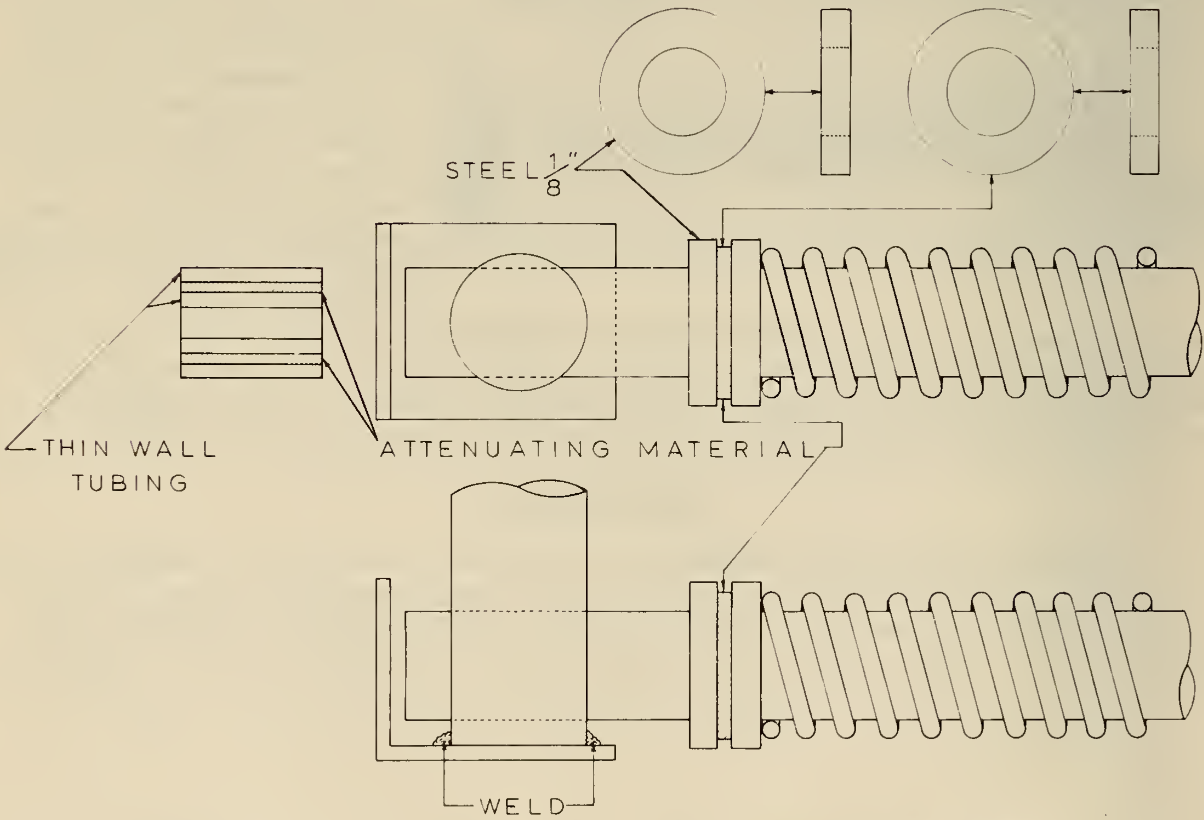

FIGURE 3. - Drawing of tail roller and tension spring noise abatement.

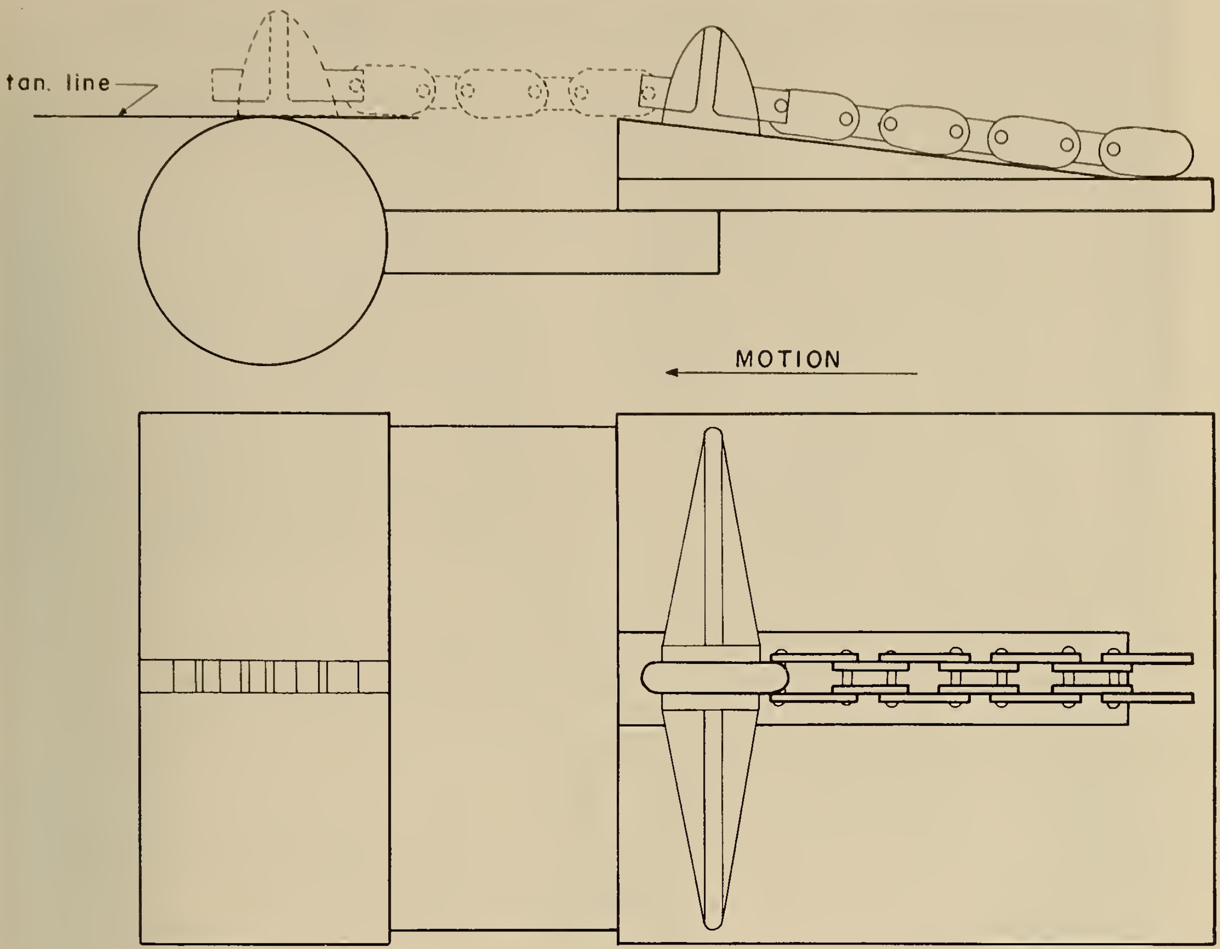

FIGURE 4. - Drawing of the ramp to aline the chain with the tangent of the tail roller.

Modification 3

The chain and its flights bear upon the top deck at three principal points, at the center (chain) and at both ends of the flights, creating a metal-to-metal friction-excited noise source. To isolate the chain mechanism from the top deck, three 3-inch-wide steel wear strips were installed all along the deck (fig. 5). These strips were isolated from the deck with 1/4-inch-thick energy-absorbing material. The deck was drilled and tapped to permit fastening of the strips with countersunk bolts. The bolt heads were also isolated as shown in figure 6. The wear strips presented a difficulty of alinement at the swivel point of the tail; therefore, a solid steel plate, isolated with energy-absorbing material, was fastened to the fixed portion of the top deck. This plate is shown in figures 5 and 7. Because of this raised plate, the conveyor sides had to be cut at the bottom to give clearance for the plate when the tail was swung right or left. The clearance cut is shown in figures 8-9.

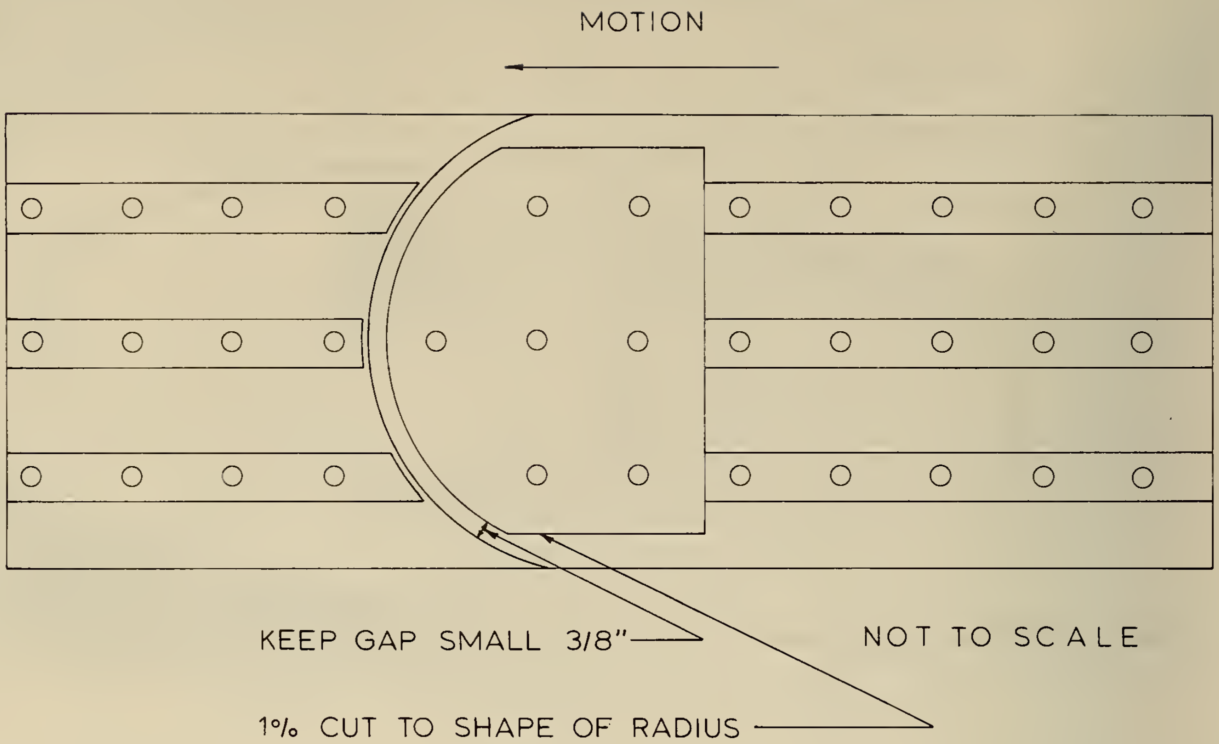

FIGURE 5. - Positioning of isolating wear strips and swivel plate on top deck.

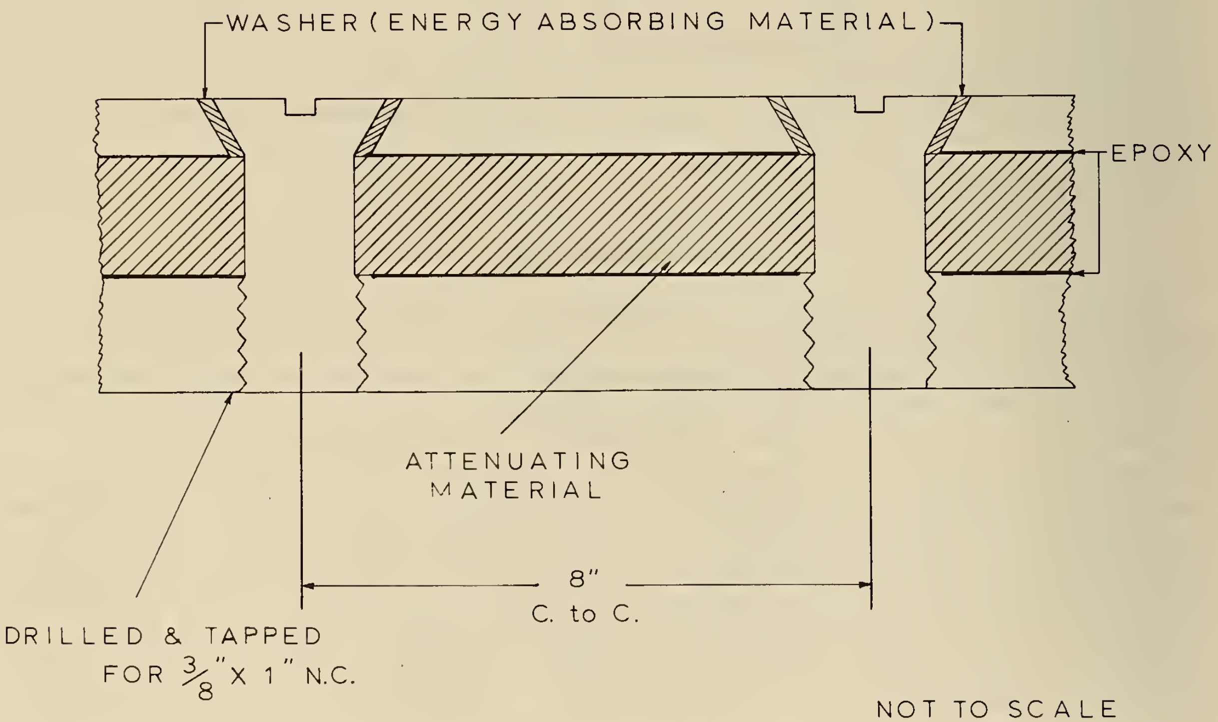

FIGURE 6. - Isolation of wear strip bolt heads.

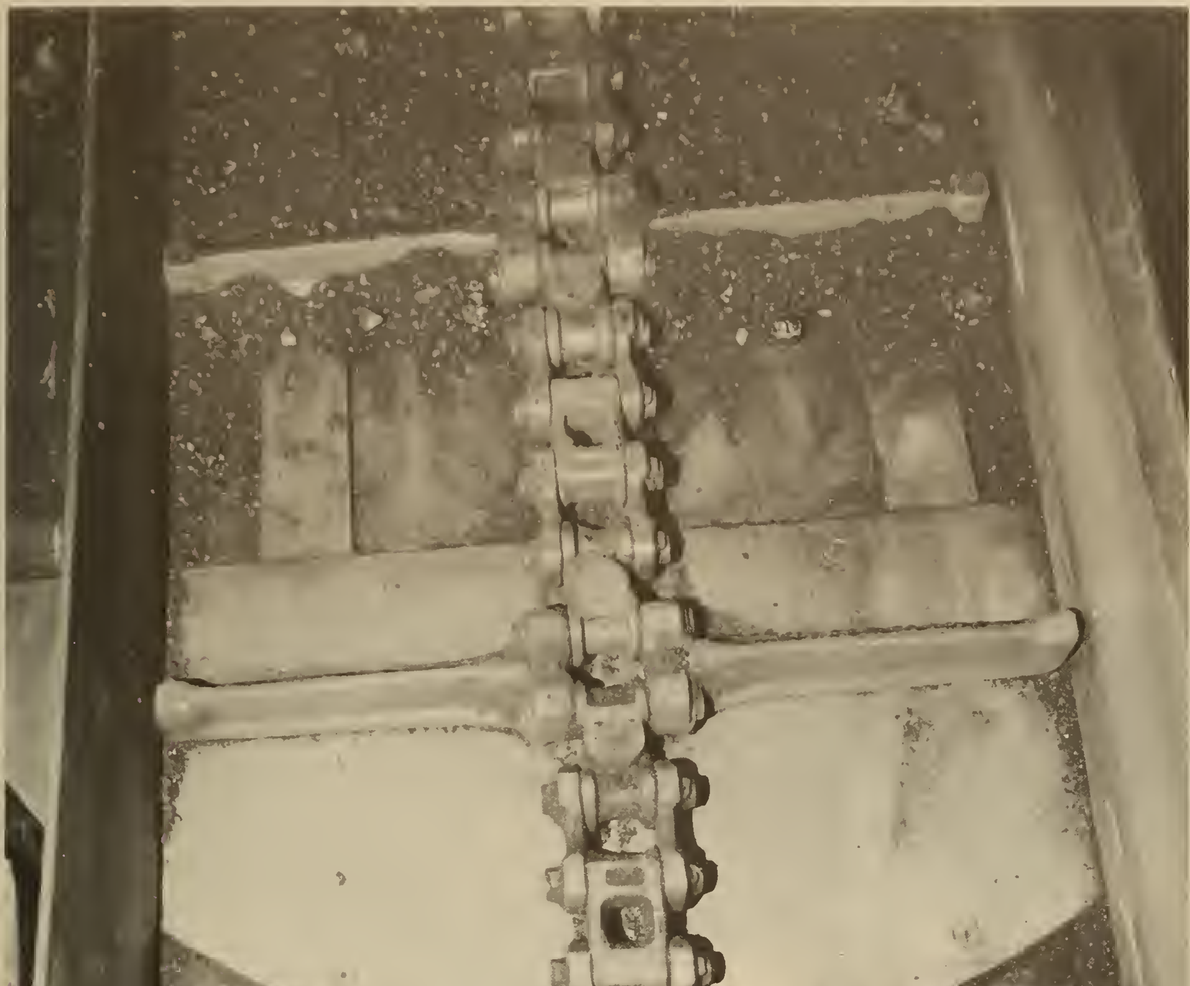

FIGURE 7. - Isolated swivel plate on top deck.

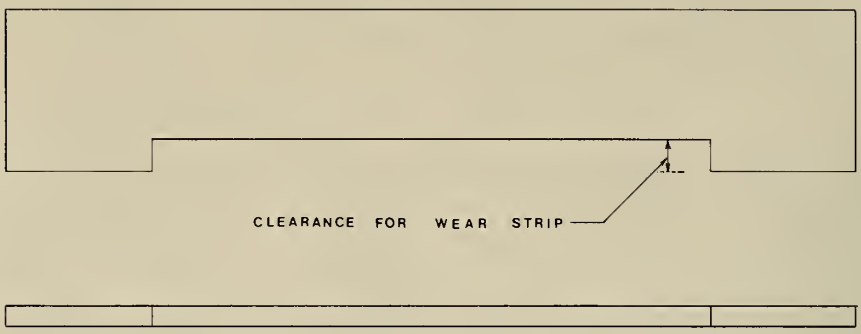

FIGURE 8. - Details of the clearance cut in the side plates at the swivel joint.

FIGURE 9. - View of the side plate clearance cut at the swivel joint.

Modification 4

At the head end of the conveyor, the chain is driven by a powered sprocket. The chain and its flights tend to follow around the sprocket and thereby impact the top deck at this point creating a noise source. Figures 10-11 show an isolated wear plate installed across the head deck to abate this noise source. Figure 12 shows an end view of this plate with 1/4-inch-thick energy-absorbing material between the plate and the deck.

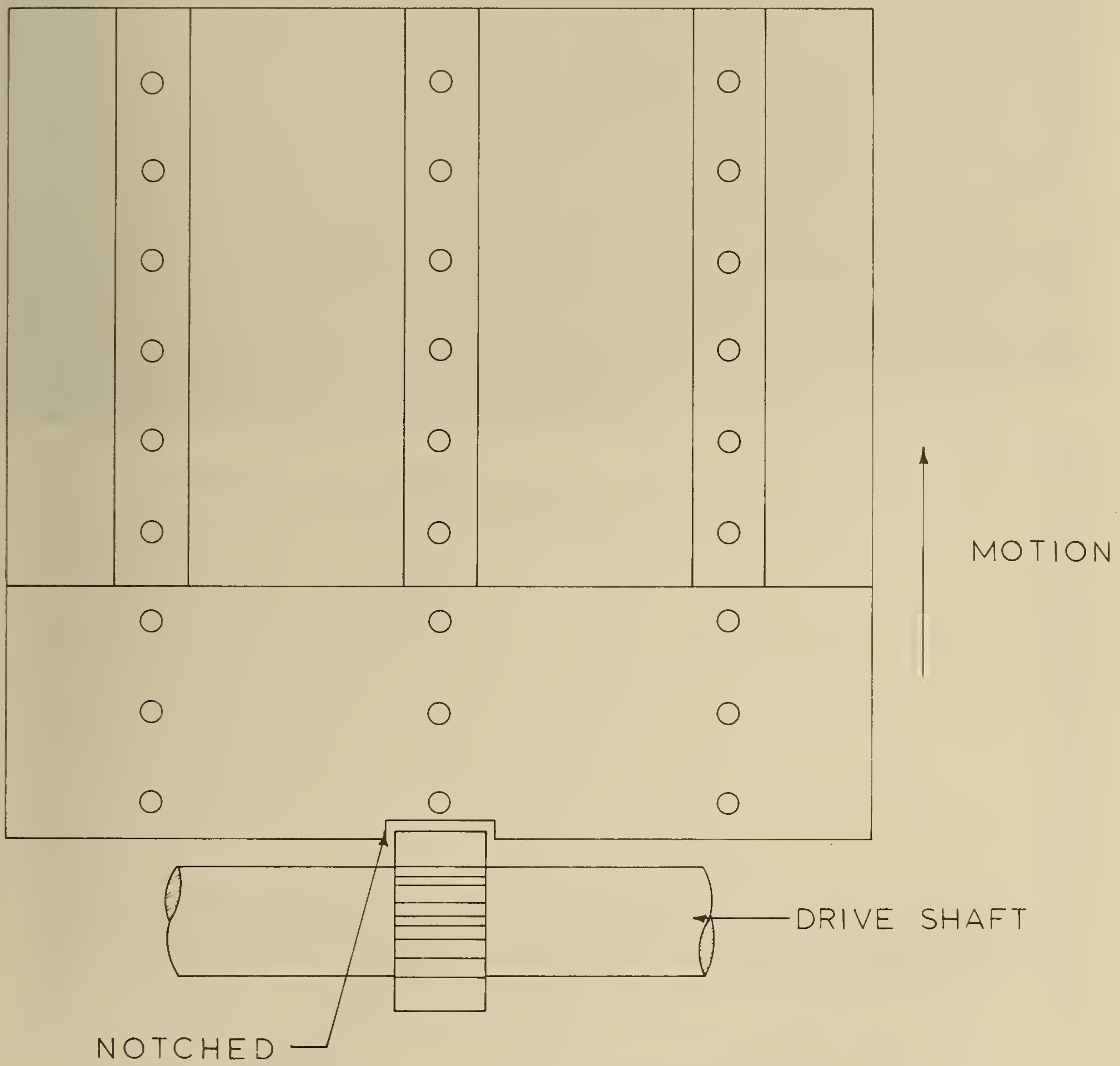

FIGURE 10. - Head end isolated wear plate.

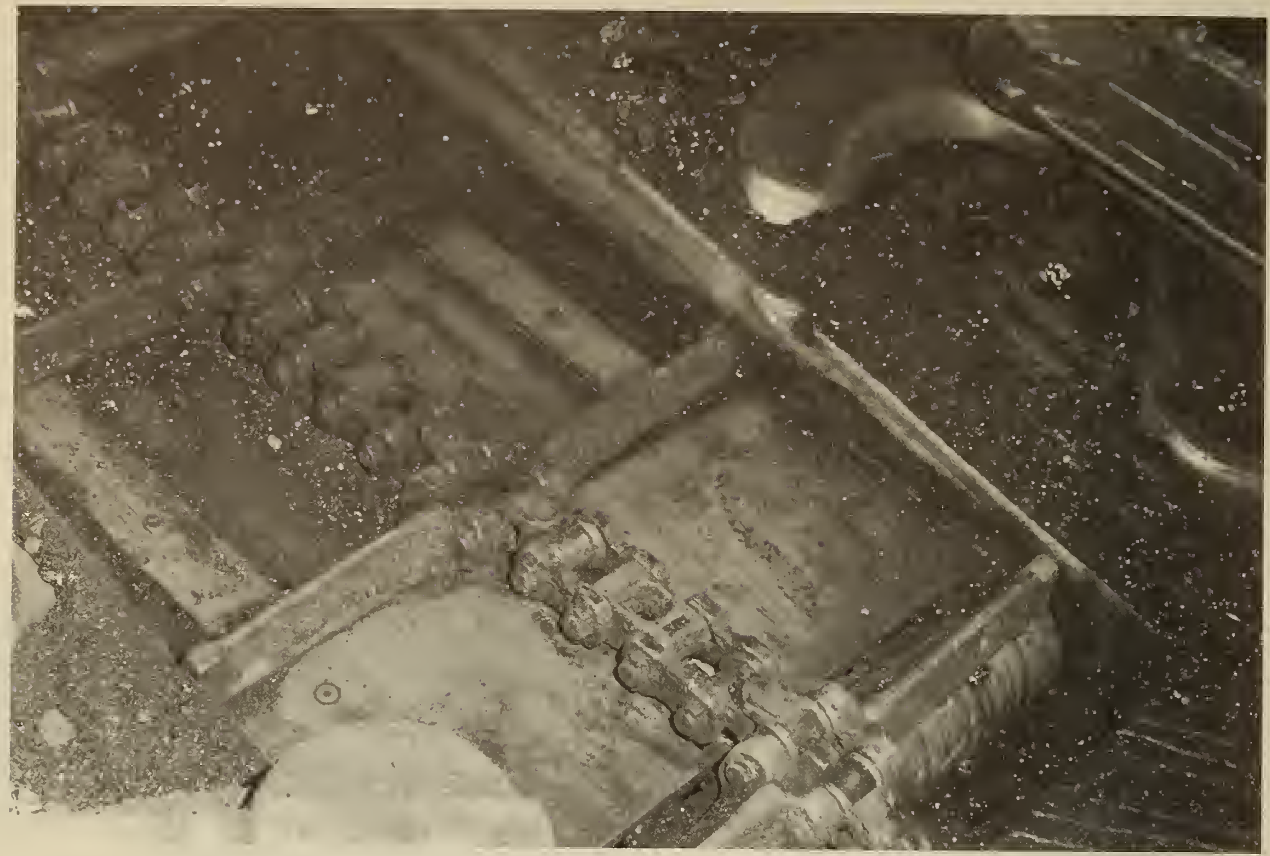

FIGURE 11. - Isolated wear plate at the head end of the conveyor.

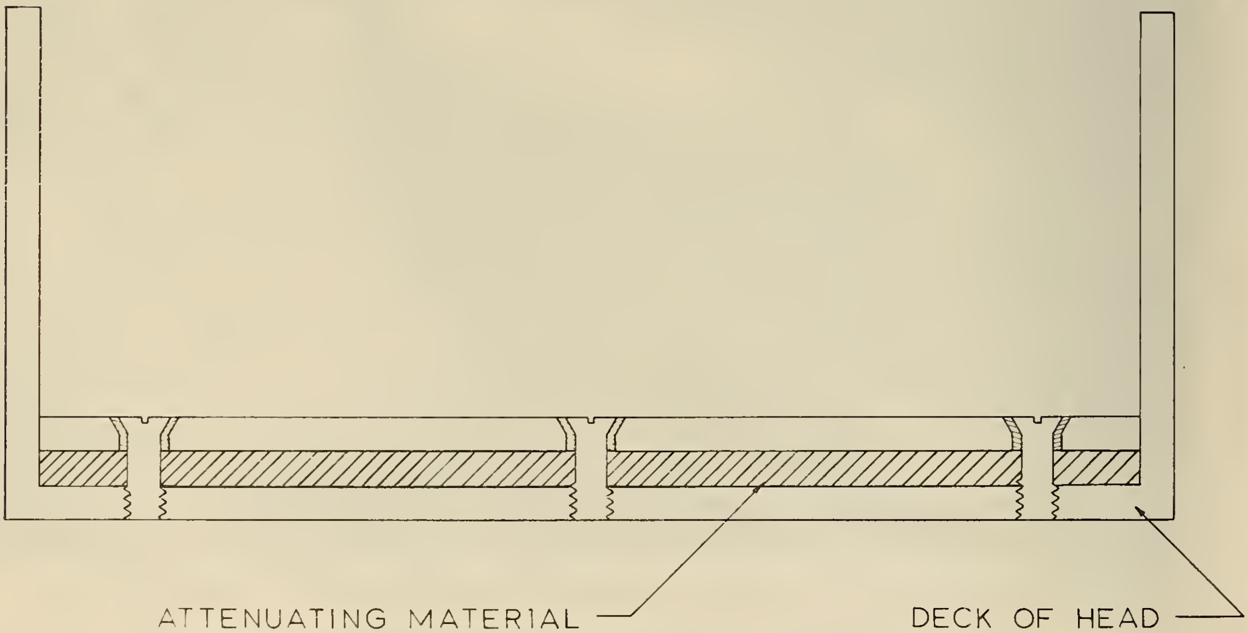

FIGURE 12. - End view drawing of the wear plate at the head end.

Modification 5

The sides of the conveyor top deck were found to be large surface noise radiators that had to be dampened. Sheets of energy-absorbing or damping material were epoxied to these sides on their outer surfaces. For purposes of ruggedness and durability, a small steel angle was welded to the top of the sides shown in figure 13. It should be mentioned that an epoxy system of fastening necessitates cleaning all contact surfaces by sand blasting. For insured durability, stud welding, in addition to epoxy but not in lieu of, may be used.

Thus far, all modifications concerned the top deck of the conveyor. The following are modifications to the lower or return deck.

Modification 6

As the chain leaves the stationary lower deck at the hinge point to enter the movable head return deck, the downward force of the chain causes an impact of stationary deck creating a noise source. At this point an isolated wear shoe was installed by cutting out a section of the stationary deck and welding in a prefabricated wear shoe. A side view of the wear shoe is shown in figure 14; a top and end view is shown in figure 15, and figure 16 is a photograph of this modification. Figure 14 also shows wear strips installed on the head portion of the lower deck.

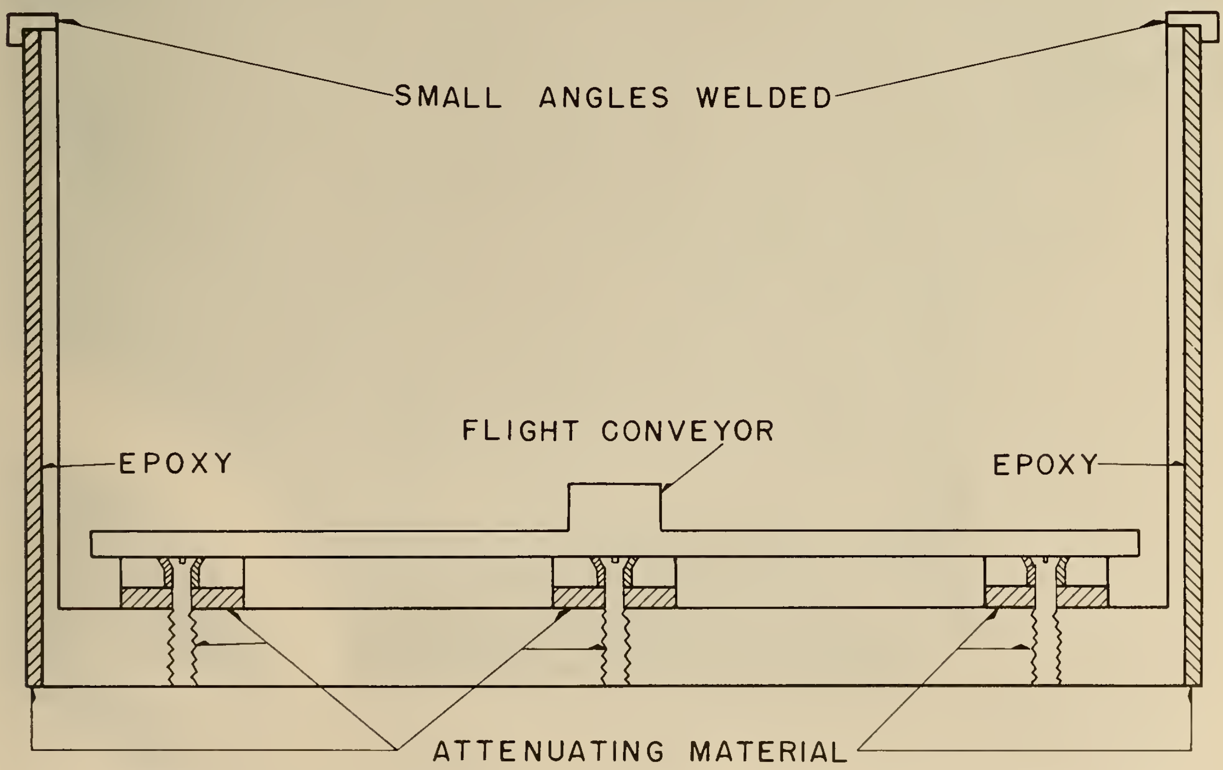

FIGURE 13. - Steel angles welded to sides to protect attenuating material.

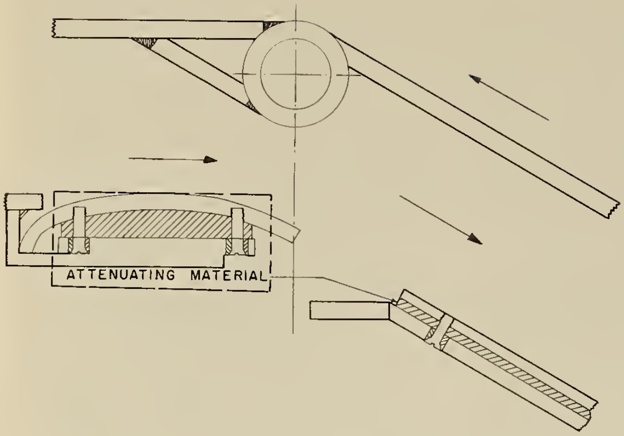

FIGURE 14. - Side view of upper and lower decks showing an attenuated wear shoe at the hinge point on the lower deck.

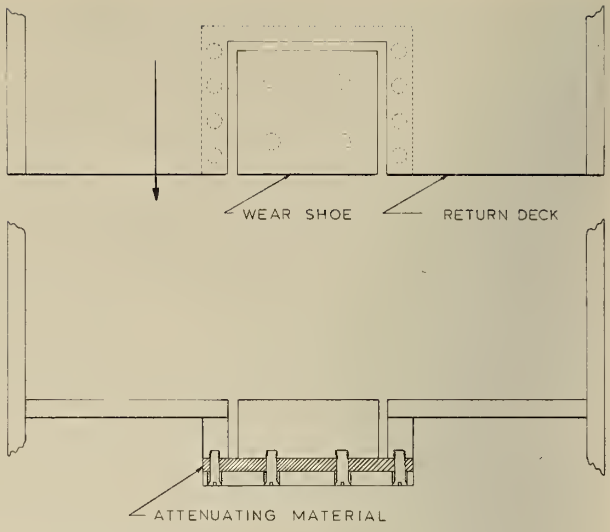

FIGURE 15. - Top and end views of the wear shoe at the hinge point of the lower deck.

FIGURE 16. - Underside view of wear shoe installation on return deck.

FIGURE 17. - Underside of tail section where a wear shoe should be installed.

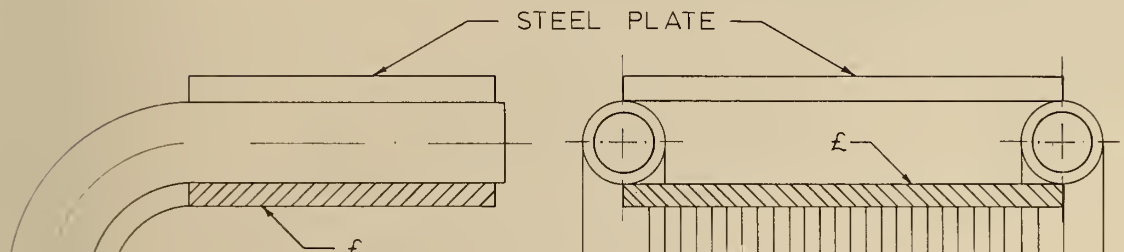

FIGURE 18. - Attenuation of a cab.

Modification 7

A wear shoe such as described in modification 6 should be installed at the tail end of the lower or return deck to abate the impact of the chain as it leaves the tail roller and enters the lower deck on its return path. Figure 17 is a view under the tail section. These installations should be placed at the lower center of the photograph.

If a cab is installed at the operator's position, damping material should be fastened to the inside of any large surface, such as shown in figure 18, so that the cab is not a noise radiator.

An ensuing contract with Foster-Miller Associates entitled "Innovative Conveyor Designs" deserves an interim report. The conveyor will be principally an elastic belt design with the usual steel chain and flights superimposed on the belt of the main section. The swing section will be separate to allow raising and lowering, left and right. An artist's conception is shown in figure 19. Thus far, reports estimate that this conveyor noise level will be below 90 dbA.

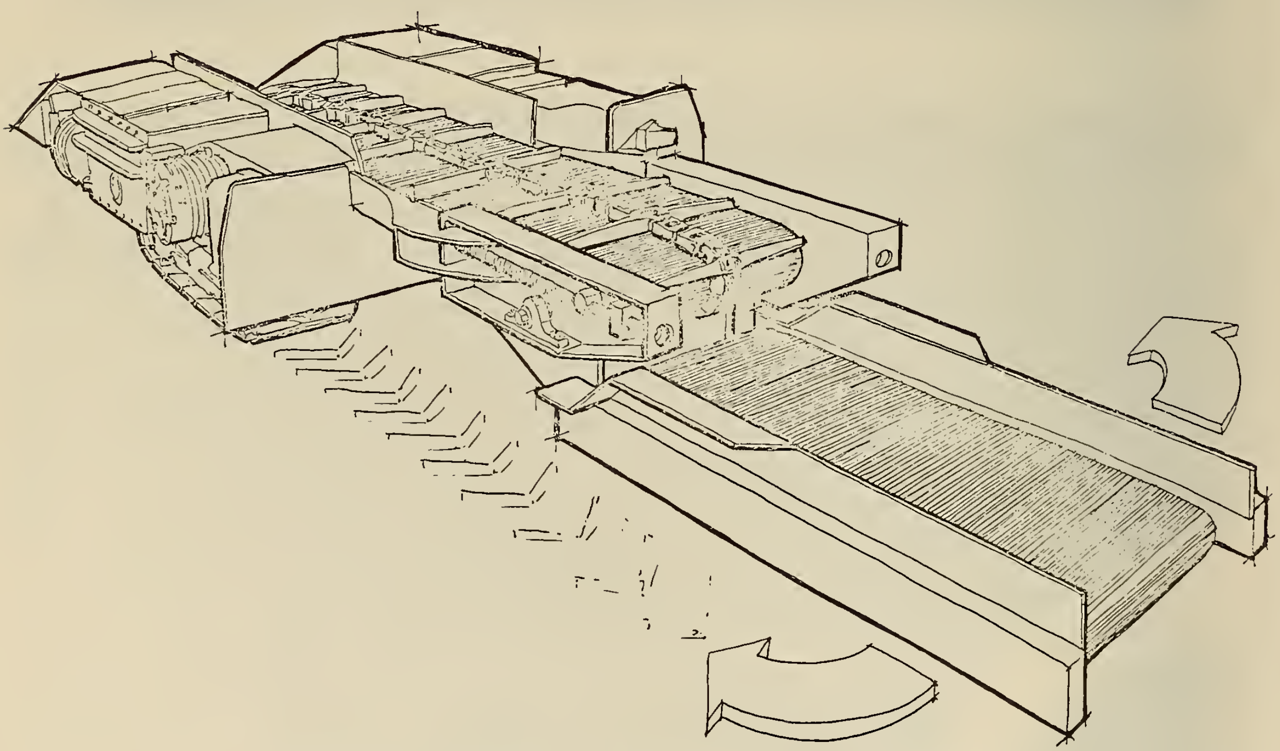

FIGURE 19. - Artist conception of a quiet belt conveyor.

CONCLUSION

This description of noise sources of a loader conveyor and their control is that of one specific manufacturer; nevertheless, the sources are all representative of those inherent in any type of chain-flight machine.

Some initiative or innovation for the modification is necessary. For instance, the deck material was found to be so hard that a special hydraulic drill press had to be devised to permit drilling; also, tapping of the hole had to be done slowly and with great care to keep from breaking taps.

All modifications to the loader are applicable to the mining machine, but the drum head noise sources of the miner were not investigated. This work may necessitate a separate study.

The goal of 90 dbA has not been achieved, but a reduction of about 7 db will more than double the time that the machine can be operated during an 8-hour shift.

It has been estimated that the cost of a retrofit of the loader would be about one-tenth of the original purchase price of the machine.

INSTRUMENTS FOR NOISE CONTROL

by

H. K. Sacks[1]

ABSTRACT

The emergence of Federal and local noise regulations that limit occupational noise exposure have resulted in the marketing of a variety of noise monitors. The most sophisticated and potentially useful of these devices is called the personal audio dosimeter.

Briefly stated, personal audio dosimetry can be an accurate and economical technique for isolating noise problems in hazardous locations inaccessible to sound level meters and surveyors. However, without specific regulations detailing their performance and use, dosimeters cannot reach this goal. The Bureau of Mines and the Mining Enforcement and Safety Administration have made evaluations and studies of commercial dosimeters. The overall results and conclusions are presented.

INTRODUCTION

Since the inception of government regulations on worker noise exposure, a variety of noise measuring instruments have appeared in the market place. They are variously called noise meters, noise hazard meters, integrating sound level meters, or personal audio dosimeters. We will confine our discussion to those instruments that measure noise exposure as required by the Coal Mine Health and Safety Act of 1969. Where these instruments differ significantly from other varieties, this will be pointed out.

OPERATION

Figure 1 is a functional representation of a personal audio dosimeter. The first section consists of a sound level meter designed to measure the

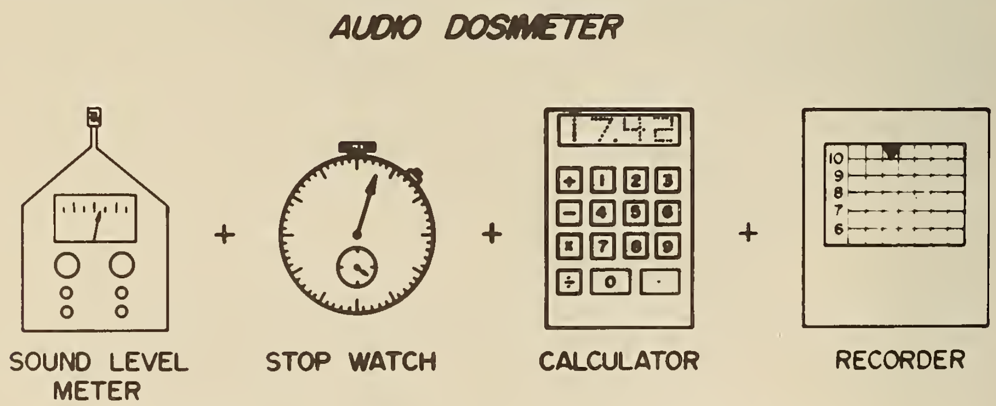

FIGURE 1. - Functional diagram of audio dosimeter.

[1]Supervisory electrical engineer, Federal Bureau of Mines, Pittsburgh Mining and Safety Research Center, Industrial Hazards and Communications, Pittsburgh, Pa.

A-weighted sound level as specified in ANSI (American National Standards Institute) standard S1.4-1971. The output of this section is the A-weighted sound level, L_A, and for this class of instruments, the meter is accurate in the range of 90 to 115 dbA.

The second part of the dosimeter is shown as a calculator and stopwatch because it computes the noise exposure caused by the sound level measured in the first section. Table 1 gives three examples of noise exposure criteria in use or proposed. The chart shows the maximum allowable exposure time for an 8-hour shift at various sound levels. Column A gives the limits used in the Coal Mine Health and Safety Act. Only those units that calculate exposure as shown in column A and indicate when a level of 115 dbA has been exceeded are suitable for coal mine use.

TABLE 1. - Noise exposure criteria

L, dbA[1]	Allowed exposure time, hours		
	A[2]	B[3]	C[4]
85	-	25	8
90	8	8	2.5
95	4	2.5	.80
100	2	.80	.25
105	1	.25	.08
110	1/2	.08	.025
115	1/4	.025	.008

[1]Sound level, dbA, slow as per ANSI S1.4-1971.
[2]Coal Mine Health and Safety Act (1969) and Occupational Safety and Health Regulation.
[3]International Organization for Standardization R1999.
[4]Recommended EPA Exposure Criteria, Federal Register, v. 39, Dec. 18, 1974, p. 43802.

Exposure is calculated by dividing the actual time of exposure by the allowable time for the level measured. For example, from column A, an exposure of 1/4 hour at 110 dbA gives 1/4 ÷ 1/2 = 0.50 or 50 percent of the daily allowable exposure. If during the same day an exposure of 1 hour at 105 dbA occurred, an additional exposure of 1/1 = 1 or 100 percent would be obtained. This must be added to the previous value for a total of 150 percent, which is out of compliance. Normally, sound pressure levels do not stay constant for long periods of time, and the levels used must be averages taken over the observation time. As the observation time increases, the error in the calculated exposure can increase. A dosimeter overcomes this problem by continuously measuring the sound level and accumulating the correct exposure.

As shown in colum A, table 1, there is no exposure time limit below 90 dbA. The dosimeter automatically stops accumulating exposure below this level.

The third section of figure 1 is a recorder. Its function is to keep a record of the total exposure for the day. In addition, there is a switch or

light that is turned on to indicate if the 115-dbA limit has been exceeded. In practice, the recording section may have several forms. Figures 2-3 show the two common ways exposures are recorded and read out. In figure 2, exposure is recorded on a mechanical counter which is part of the dosimeter. Figure 3 shows a dosimeter in which exposure is recorded internally with an electronic counter read out with a separate instrument at the end of the day. In either case, the reading is the percentage of daily allowable exposure.

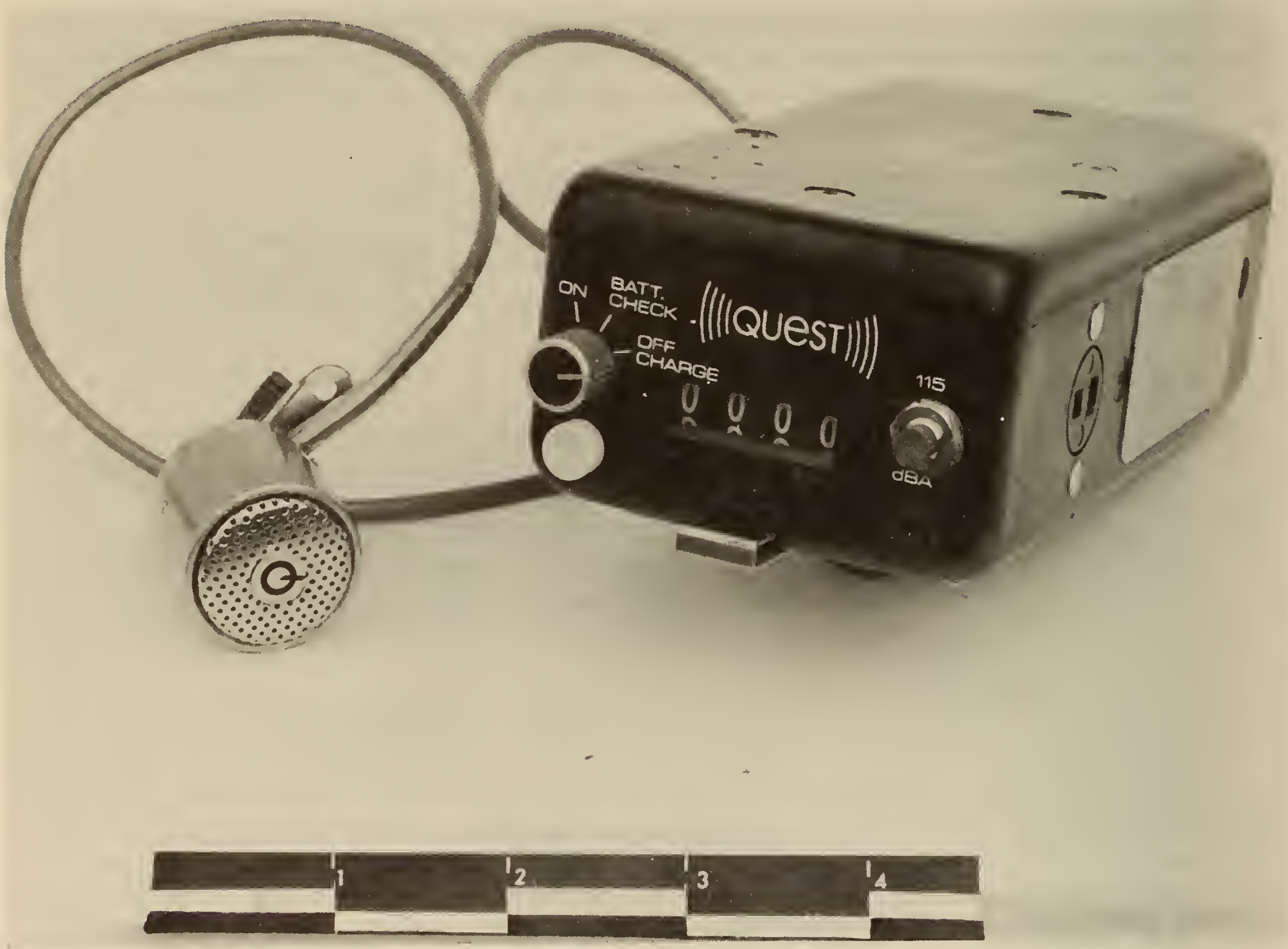

FIGURE 2. - Dosimeter with self-contained mechanical readout.

FIGURE 3. - Dosimeter with separate electronic readout device.

ADVANTAGES

Dosimeters offer two advantages over sound level meters for recording worker exposure. The most important is safety. The working face is generally a congested area, especially in low coal. The addition of one or perhaps two men to make noise measurements can present a problem. Dosimeters require no added personnel. When exposure must be measured for workers on moving machines, an obvious hazard exists. Again, dosimeters eliminate this hazard.

The second advantage is accuracy. Dosimeters eliminate estimating sound levels and exposure times because they automatically account for changing conditions. They can monitor for a complete shift to give a true full shift exposure.

PROBLEM AREAS

Unfortunately, there are a number of operational and technical problems that prevent dosimeters from being the panacea for determining worker exposure. These will be briefly explained.

Instrument Accuracy

In 1972, the Bureau evaluated the commercially available instruments. Five of the eight brands tested met an overall tolerance of ±2 dbA. This is

roughly equivalent to the tolerance of a type II sound level meter. The effect on exposure is as follows. If the true exposure were 100 percent, a group of instruments with ±2 dbA tolerance would indicate exposures in the range of 76 to 132 percent. Typical results are shown in figure 4. The dark area shows the exposure recorded by 12 dosimeters (4 brands) when exposed to various levels of pink noise. In all cases, the level and time were adjusted to give an exposure of 1.0. Although this seems to be a broad range, it must be remembered that type II sound level meters fall in the same range.

Even if the instruments were more precise, the readings would depend on the day-to-day variations in true exposure so that an exposure within compliance on 1 day would not guarantee compliance of the next. A statistical study of this problem has been done in detail by D. Conn.[2] The result is that whether dosimeters or sound level meters are used, valid measurements cannot be obtained without proper sampling techniques.

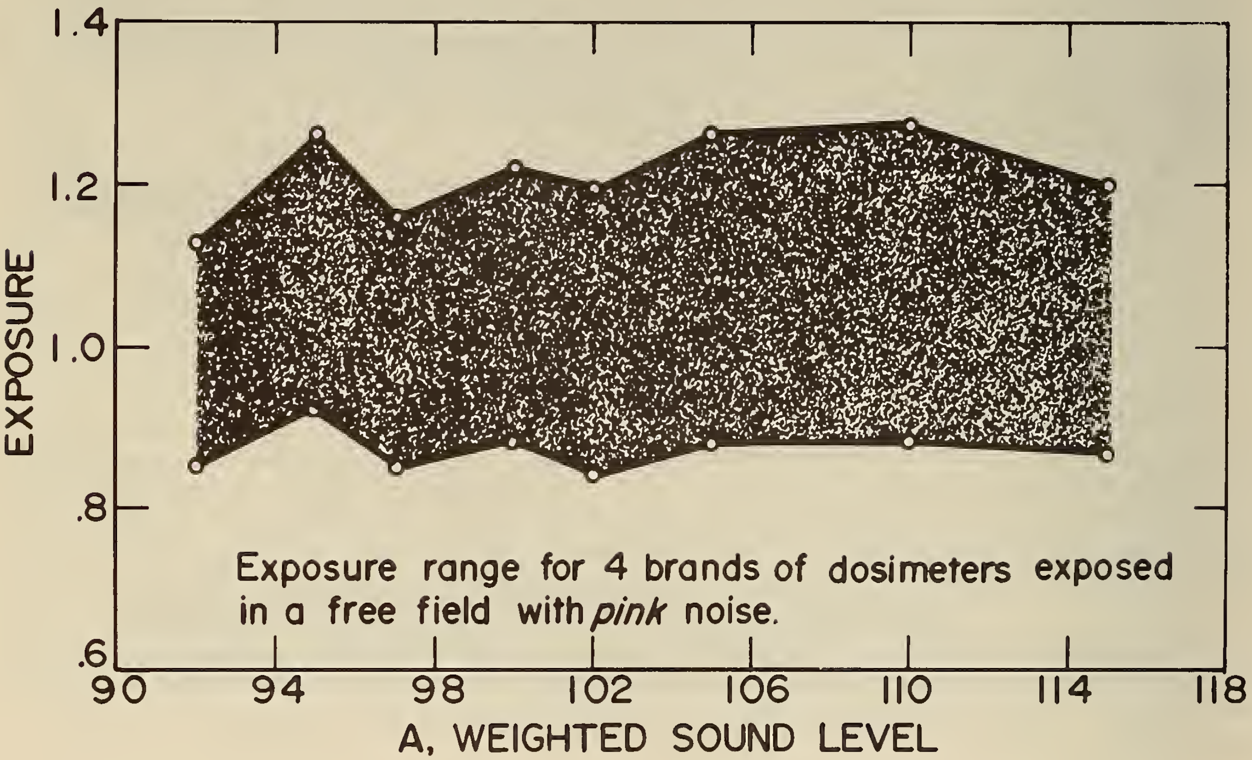

FIGURE 4. - Exposure results for 12 instruments (4 brands).

[2]Conn, D. O. III. The Audio Dosimeter--A System for Measuring Personal Noise Exposure. Pres. at Am. Ind. Hyg. Conf., May 17, 1972, San Francisco, Calif.; available for consultation at the Education and Applied Technology Div., E. I. DuPont de Nemours Co., Inc., Wilmington, Del. 19898.

Microphone Placement

A problem specific to dosimeters is concerned with microphone placement. A study done by the Pittsburgh Technical Support Group[3] showed that to obtain readings with a dosimeter comparable with a sound level meter, the microphone should be placed on the wearer's shoulder with the axis parallel to the body. The experiments were done with a microphone designed for grazing incidence in an anechoic chamber.

However, even under these conditions, large variations in measured exposure occurred as the direction of noise relative to the wearer changed. For example, with the microphone on the right shoulder and the noise coming from the left, the dosimeter measured a sound level 5.5 db lower than the true level. When the noise came from the front, the dosimeter indicated 4 db higher than actual. In this experiment, the exposure was 95 dbA for 4 hours. A sound level meter held 1 foot from the subject's most exposed ear gave calculated exposures ranging from 71 to 86 percent of the daily allowance. The dosimeter gave exposures from zero to 150 percent of the true exposure.

In actual working environments, free fields do not exist and workers generally do not remain in a fixed location, so that the aforementioned experiment is the worst case. However, in using dosimeters, some caution should be used to mount the microphone near the most exposed ear.

Maintenance

Since dosimeters are worn on workers, they are likely to be subjected to much more severe treatment than a sound level meter used by a skilled technician. Their durability has not yet been proven in underground use. An effort should be made to protect them for excessive dirt, water, cold, and shock. The microphone may be particularly sensitive to dust and moisture. Some units have dust protection; others do not.

Sound level meters are calibrated immediately before and after a survey measurement is taken. Dosimeters can be calibrated only before and after a shift. If they show a significant change, the data taken may be worthless. Batteries should also be checked before and after use to insure the unit was operational during the entire survey period.

Cost

The cost range for dosimeters is wide. The lowest priced unit is about $250; the most expensive is $750. However, the least expensive device requires a separate readout costing $600. If more than one dosimeter is to be used, the units with separate readout should be considered. A list of instruments and suppliers will be found in table 2.

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[3]Muldoon, T. L. Response Variations of a Microphone Worn on the Human Body. BuMines RI 7810, 1972, 42 pp.

TABLE 2. - Commercial audio dosimeters[1,2]

Manufacturer	Model	Separate readout required
Bendix Corp.	1150	Yes
B&K Instruments, Inc.	4425	No
Columbia Research Lab.	SPL-105	No
E. I. du Pont de Nemours & Co.	D-100	Yes
Edmont-Wilson Corp.	60-520	No
General Radio Co.	1944-9706	Yes
Tracoustics.	ND-100	Yes
Triplett Corp.	376	No
Quest Electronics.	M-6	No
Welsh Manufacturing Co.	9702	No

[1]Reference to specific trade names or manufacturers does not imply endorsement by the Bureau of Mines.
[2]This list was compiled from the best available data as of May 1974.

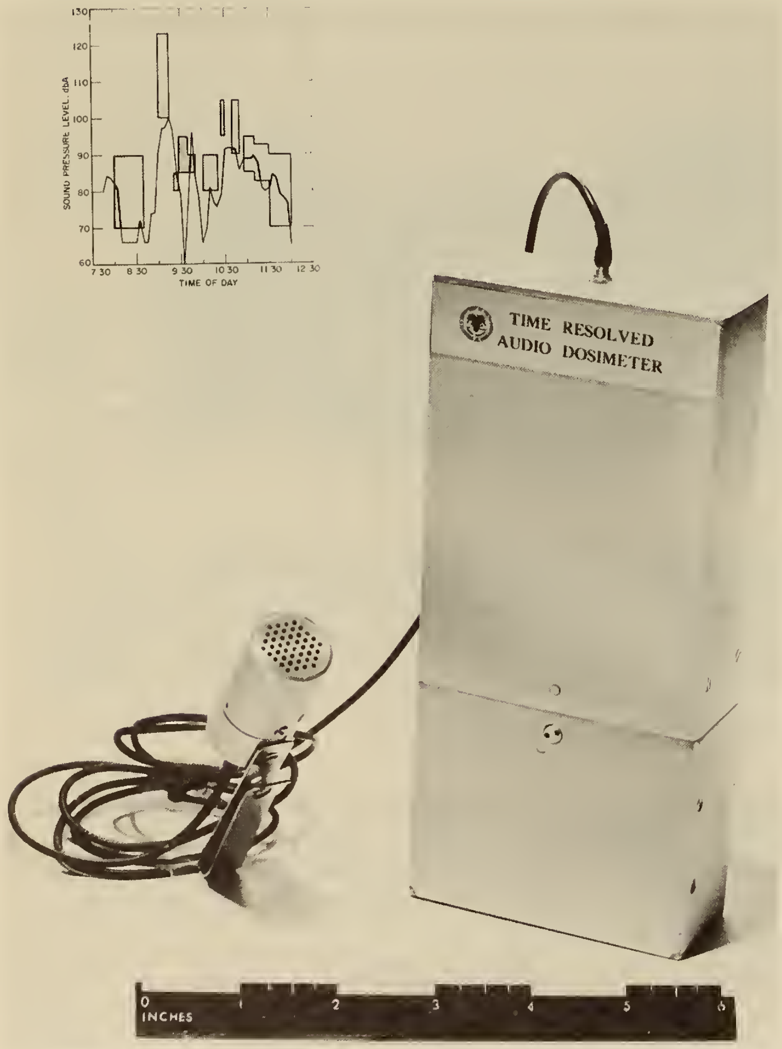

FIGURE 5. - Time resolved audio dosimeter. Insert: Typical output for 5-hour exposure.

Advanced Instrumentation

In most noise control work, a time and motion study is useful in pinpointing specific exposure problems and noise sources during a typical machine cycle. Generally, this data is obtained through extended surveys with a sound level meter and stopwatch. Tape recorders are also used occasionally. Because of the difficulty in obtaining this type of data, the Bureau has been developing a time resolved dosimeter that is readily carried and monitors noise levels for 8 hours. This unit is shown in figure 5; the curve shows a typical output for a 5-hour period. The solid blocks are an observer's estimate of levels and times during the survey.

Present plans are to use the devices in the field for studying exposures in various surface operations.

CONCLUSIONS

Audio dosimeters provide a means of getting full shift noise exposure data with relative ease and safety. However, the results require careful interpretation and cannot be used as the sole source of information. A single day's operation on one man is not conclusive evidence of conditions. Where prior experience indicates different results, a sound level meter and skilled surveyor must be used.

Finally, there are presently no regulations in regard to use of dosimeters in underground coal mines. However, as more is learned of their performance underground, it is expected that this will change.

NOISE CONTROL OF STOPER DRILLS USED FOR ROOF BOLTING IN COAL MINES

by

R. E. Manning[1]

ABSTRACT

The Federal Coal Mines Health and Safety Act of 1969 has placed stringent limitations on the noise levels in which employees may work. A current research program at U.S. Steel is aimed at developing methods of controlling both the exhaust air noise and the mechanical noise of a stoper drill, a pneumatic percussive tool used for roof-bolting purposes in coal mines that has an approximate air consumption of 100 ft^3/min. This program is being performed under a contract between USS Engineers and Consultants, Inc., and the Pittsburgh Mining and Safety Research Center of the Federal Bureau of Mines.

The program investigated new muffler designs for reduced air exhaust noise, new enclosure designs for control of the noise emanating from the drill cylinder surface, and new acoustic absorptive units to control percussion noise of the drill rod. Field tests were performed on the pneumatic drill with all three elements of the noise control system attached; two mufflers, one enclosure, and several absorptive units for the drill rod were tested in specific combinations. Noise readings with the 6-inch muffler indicated levels in the mid-90-dbA region. Noise readings with the 10-inch muffler indicated levels in the low 90-dbA region.

INTRODUCTION

The Federal Coal Mine Health and Safety Act of 1969 has placed stringent limitations on the noise levels in which employees may work. This act can result in both increased labor costs because of noise-exposure time limitations and in high capital costs for modification of present equipment and the design of new equipment to comply with the law. The development of new noise-control systems is thus of immediate interest to industry.

Specifically, a need exists for more effective noise control in the mining industry, such as the mining of coal, iron ore, and limestone. One noise problem common to all mining operations results from the use of pneumatic pressure drills of different sizes. New muffler designs with the required acoustic performance for the air exhaust, new enclosure designs for control of the noise emanating from the drill cylinder surface, and new control units for the percussion noise of the drill rod are needed.

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[1]Senior research engineer, U.S. Steel Research Laboratory, Monroeville, Pa.

At present, work is being done in this field by U.S. Steel Research under a contract between USS Engineers and Consultants, Inc., and the Pittsburgh Mining and Safety Research Center of the Federal Bureau of Mines. An earlier report[2] prepared under this contract describes the initial work completed on the development of a muffler for a stoper drill (RP38E) manufactured by the Ingersoll-Rand Co.[3] and used for roof bolting in coal mines. Four mufflers were designed during the previous work; one of the mufflers was designed with a kidney shape to facilitate installation around the air leg of the drill. The mufflers were designed with the aid of a digital computer program that predicts the acoustic performance of mufflers. The present paper extends the previous work to kidney-shaped mufflers of different designs with various internal-chamber configurations and lengths.

MUFFLER DESIGN

Following the design, construction, and testing of the first kidney-shaped muffler,[4] work on improving the design muffler system has continued. The original kidney-shaped muffler 1 is shown in figure 1. This muffler was designed using a combined approach of analysis of acoustic performance by a digital computer program and testing using a simulated loudspeaker noise source.

Muffler 2 was the same as muffler 1 except that one additional 1/2-inch-thick neoprene liner was added to the second baffle face in the first chamber. The new second chamber in muffler 2 consists of the following alterations: (1) The 1/2-inch-ID tube in the second chamber was cut off and removed, and the hole in the baffle between the first and second chambers was covered, (2) the tube sections in both 1-1/8-inch-OD tubes in the second chamber were cut off and removed so that the tube lengths protruding into the second chamber from the first and third chambers were 1/2 inch long, and (3) 1/2-inch-thick neoprene liners were placed on the circumference and both baffles of the second chamber.

Muffler 3 was the same as muffler 2 except that there was no second chamber; and the 1-3/4-inch-OD 20-gage tube was used between the third and fourth chambers. The length of muffler 3 was approximately 6 inches.

All three mufflers were fabricated using bending, shearing, punching, and welding operations.

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[2] Manning, R. E. Muffler for Pneumatic Drill. BuMines Open File Rept. 28-73, 1973, 81 pp.; available for consultation at the Bureau of Mines libraries in Pittsburgh, Pa., Denver, Colo., Twin Cities, Minn., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Washington, D.C.; and from National Technical Information Service, Springfield, Va., PB 220 372.

[3] Reference to specific manufacturers or products does not imply endorsement by the Bureau of Mines.

[4] Work cited in footnote 2.

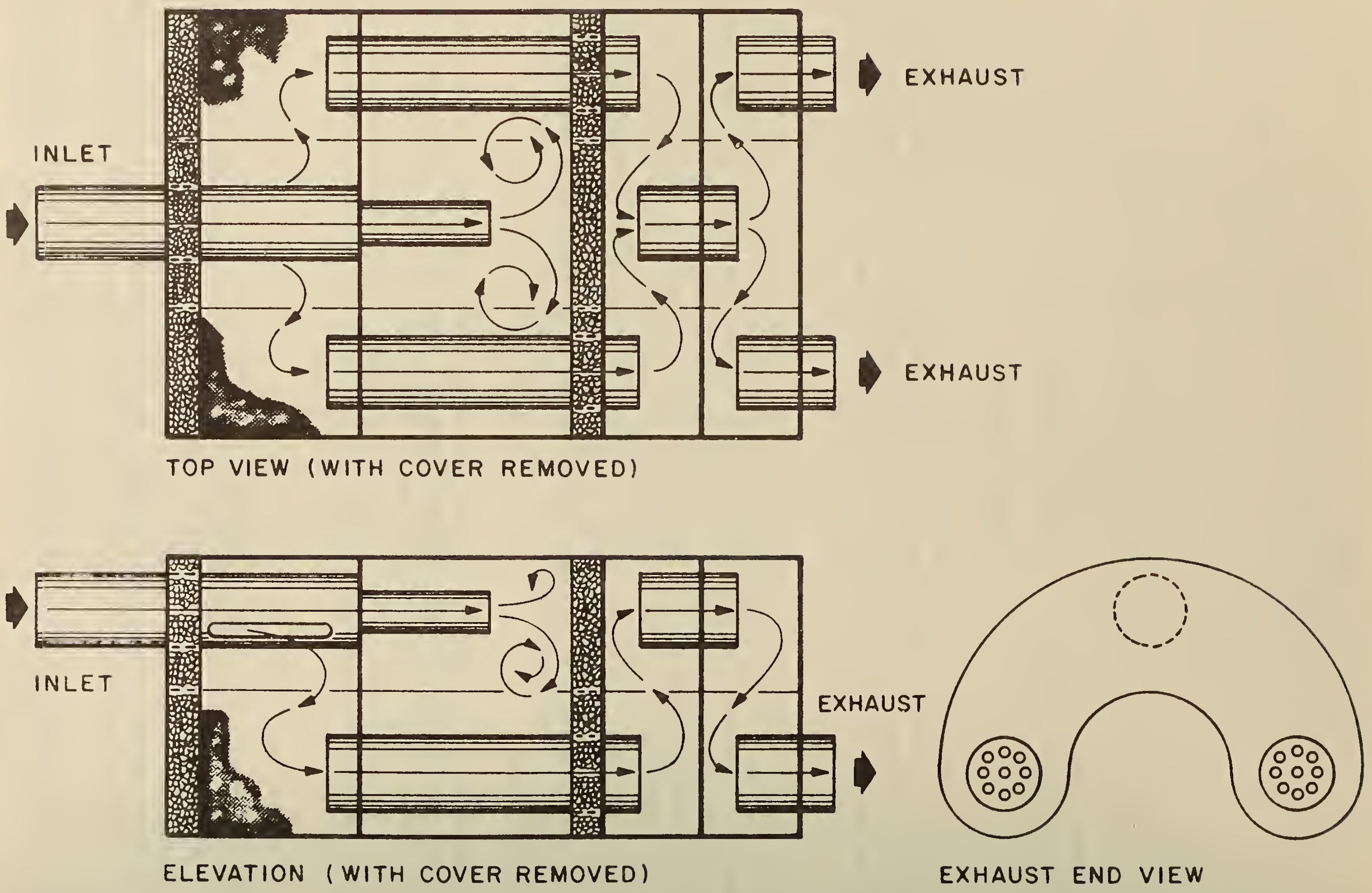


FIGURE 1. - Configuration of muffler 1.

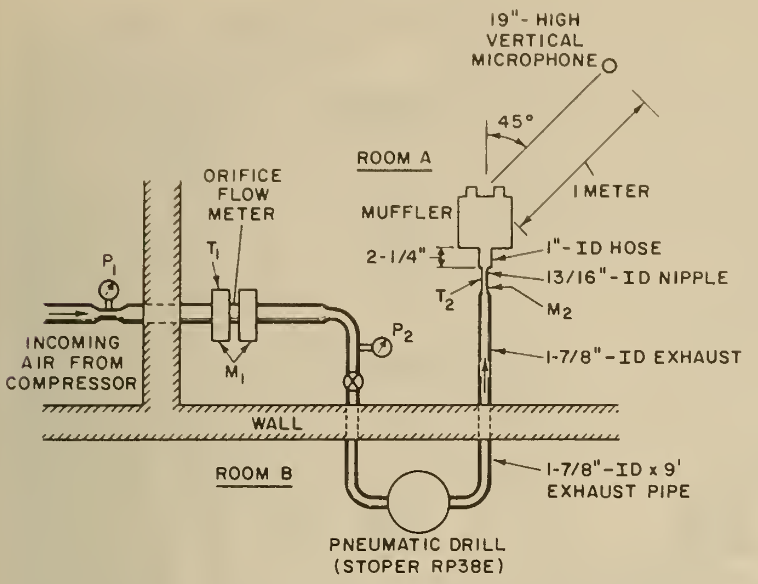


FIGURE 2. - Setup for exhaust noise tests on stoper drill at U.S. Steel Research Laboratory.

FIGURE 3. - Pneumatic drill in room B with drill air exhaust pipe going into room A.

EXHAUST AIR NOISE LABORATORY TEST CONDITIONS

The experimental work to determine acoustic levels and develop fluid-mechanics information on the mufflers was performed at U.S. Steel Research. A schematic drawing of the equipment setup used is shown in figure 2.

Exhaust noise measurements were taken with the same stoper drill (RP38E) used in the previous work. The drill was mounted in room B as shown in figure 3 and was pressurized with a portable Spiro-Flo XL-175S compressor (also manufactured by Ingersoll-Rand Co.). This compressor has a maximum output of 175 ft^3/min and a maximum outlet pressure of 125 psig. As illustrated in figure 2, the air discharge is transmitted through a double wall by an exhaust pipe into another room (room A). Through this installation, the mechanical noise of the drill is separated acoustically from the air exhaust noise.

Acoustical pressure measurements were taken with a 1-inch microphone, Bruel and Kjaer (B&K) type 4131. The electrical signals generated by the microphone were amplified with a B&K type 2603 microphone amplifier and filtered into 1/3-octave bands by a B&K type 1612 band-pass filter set. In addition, a 10-Hz filter in a B&K type heterodyne slave filter set 2020 was used to obtain a more detailed noise spectrum. Analog signals were then converted to graphical form by a B&K type 2305 graphic sound level recorder. The basic sound-detection equipment using 1/3-octave-band filters is shown in figure 4.

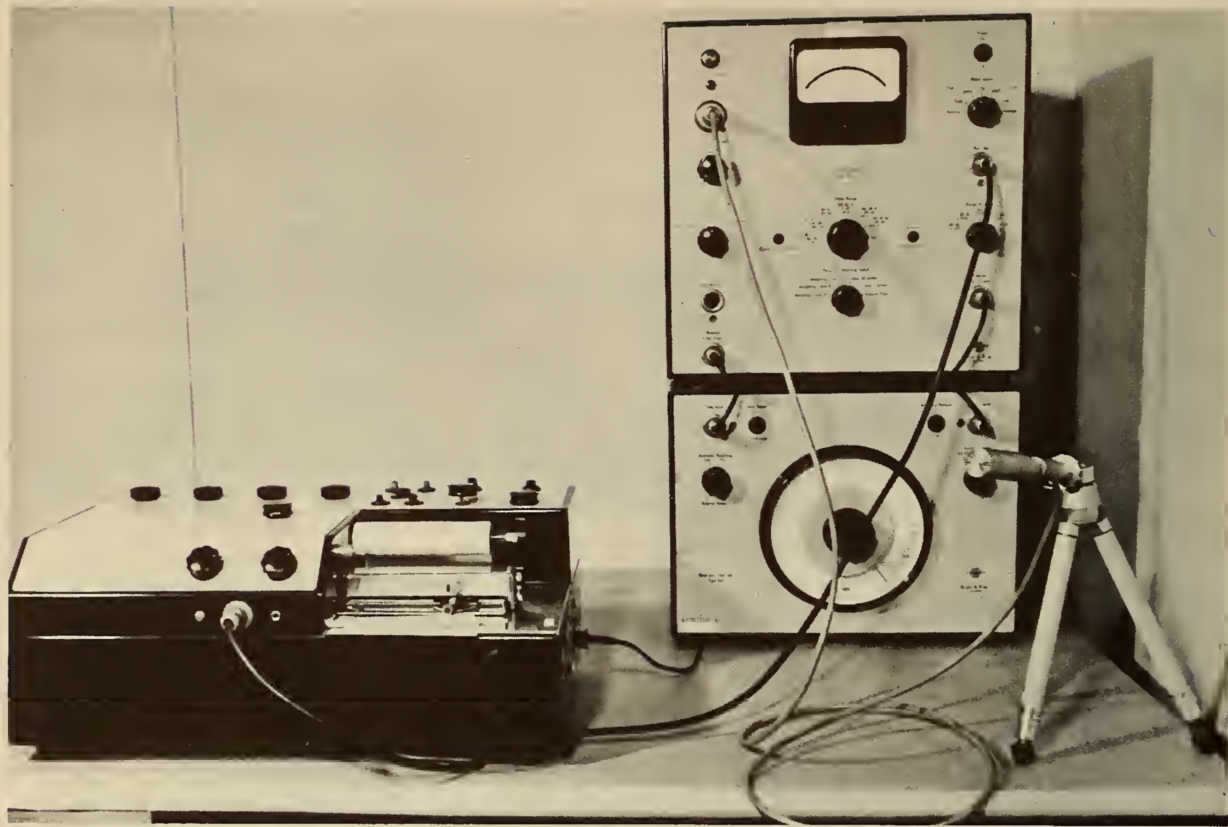


FIGURE 4. - Basic sound-detection equipment using 1/3-octave-band filters.

The exhaust noise measurements were made for the drill when used without a muffler and when used with three variations of the muffler (mufflers 1, 2, and 3). The basic measurements recorded are in 1/3-octave bands, some of which are shown in figures 5-6. For each muffler configuration, the incoming air pressures to the drill were matintained at 100 and 75 psig under no-load condition, and the microphone was placed at a location 1 meter from the exhaust in room A. The overall noise levels for each muffler conditions for these tests and for the remainder of the operating drill tests are given in table 1. Table 2 defines the nomenclature used in table 1.

TABLE 1. - Summary of exhaust noise test results for stoper drill RP38E[1]

Muffler condition	P_1, psig	T_1, °F	M_1, psi	$\dot{Q}$, ft^3/min	P_2, psig	T_2, °F	M_2, psi	Noise, dbA	Figure reference: 1/3-octave-band filter	Figure reference: 10-Hz filter
EXHAUST NOISE TEST[2]										
1. Exhaust noise with no muffler; microphone placed 1 meter away from 1-inch-ID hose in room A with same orientation as shown in figure 2.	106	103	3.52	103	96-102	33	-0.58	113	5	11
	80	105	2.20	94	73- 77	52	-.22	110	6	12
2. Exhaust noise with kidney muffler 1.	107	114	3.23	99	97-101	51	.73	84	-	-
	82	110	2.40	97	73- 77	53	.40	84	-	-
3A. Exhaust noise with kidney muffler 2.	104	116	3.47	104	100	52	1.56	83	-	-
	83	109	2.59	99	75	45	1.00	80	-	-
3B. Exhaust noise with muffler 2 (1/2-inch-ID hole to second chamber blocked).	104	120	3.52	105	100	53	1.61	84	-	-
	83	109	2.59	100	75	49	.89	80	-	-
3C. Exhaust noise with muffler 2 (no disks on two outlets of last chamber).	104	111	3.52	104	100	46	.15	88	-	-
	85	118	2.69	102	75	57	.07	86	-	-
3D. Exhaust noise with muffler 2 (new second chamber).	107	106	3.08	98	100	45	1.35	79	5	11
	82	93	2.10	90	75	40	1.20	77	6	12
3E. Exhaust noise with muffler 2 (new second chamber and no disks on outlet of last chamber).	106	110	3.13	96	100	44	.29	86	-	-
	82	93	2.10	90	75	39	.19	84	-	-
4A. Exhaust noise with muffler 3.	105	117	3.42	103	100	51	1.69	84	-	-
	81	111	2.54	100	75	53	.88	83	-	-
4B. Exhaust noise with muffler 3 (no disks on outlet of last chamber).	105	128	3.52	105	100	59	.00	94	-	-
	85	120	2.69	102	74- 79	58	.00	93	-	-
TOTAL NOISE TESTS[3]										
5. No muffler.............	108	98	3.38	99	100	-	-	121	8	-
	80	98	2.45	98	75	-	-	118	9	-

[1]The terms used in the column headings are defined in table 2.

[2]The test setup for the exhaust-noise tests is illustrated in figure 2.

[3]The arrangement of the microphone and the drill in the total noise tests is illustrated in figure 10. The microphone was positioned (in room B) 1 meter away from the exhaust--the 1-1/2-inch-diameter hole in the adapter, which fits around the air leg. The microphone was placed in a vertical position, 23 inches above the floor and at an angle of 45° from the axis of the exhaust.

TABLE 2. - Nomenclature for terms used in table 1

Term	Definition
P_1	Inlet air pressure to orifice flow meter (measured by Ashcroft mechanical gage in 1-inch-ID pipe).
T_1	Inlet air temperature of air to orifice flowmeter (measured by iron-constantan thermocouple).
M_1	Differential air pressure across orifice flowmeter (measured by Meriam manometer).
$\dot{Q}$	Calculated airflow rate $\left(\text{proportional to } \sqrt{\frac{M_1 T_1}{P_1}}\right)$.
P_2	Inlet air temperature to muffler (measured by iron-constantan thermocouple).
M_2	Back pressure of muffler (measured by Meriam manometer in 13/16-inch-ID nipple).

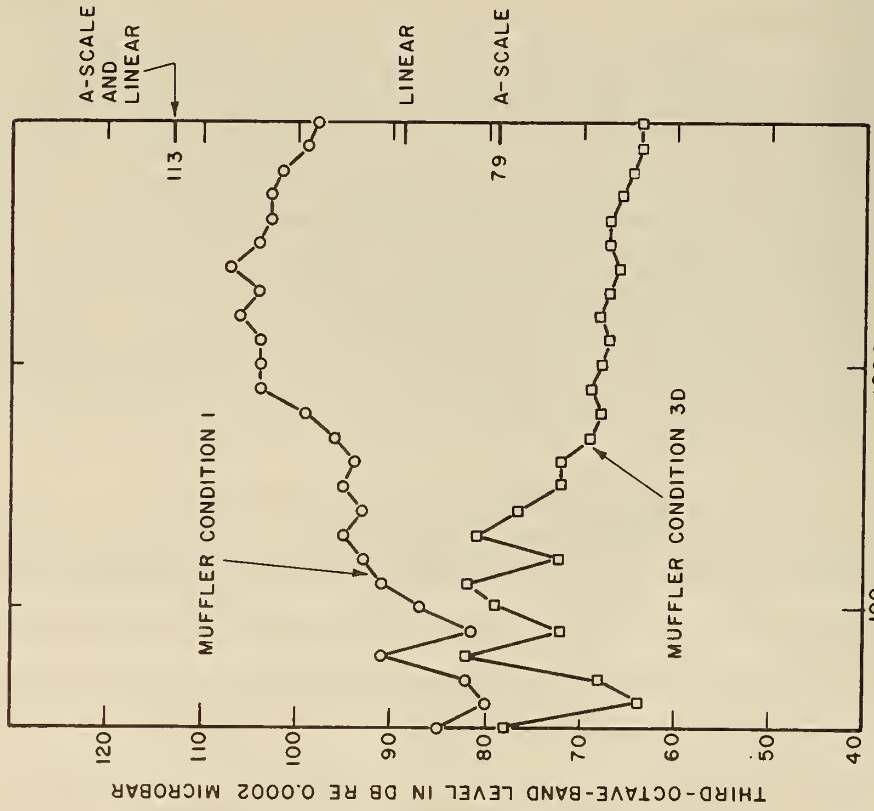


FIGURE 5. - Exhaust noise, 100 psig.

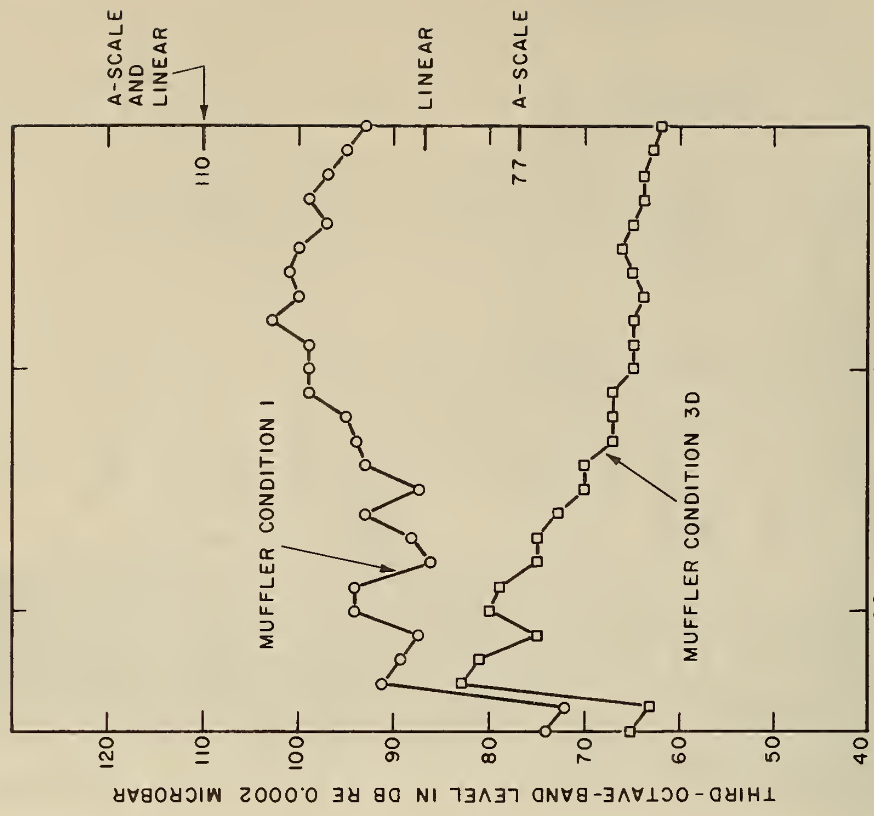


FIGURE 6. - Exhaust noise, 75 psig.

For each test, the thermodynamic information listed in table 1 was recorded. The orifice meter used to measure the airflow rate was manufactured by the Foxboro Co., Foxboro, Mass. It is basically a round-hole orifice with flange taps with a 2-inch-diameter pipe (schedule 40) line size. The specifications for this flowmeter are given in Foxboro data sheet No. 73N-47196 (September 24, 1973). A photograph showing the test setup for determining the fluid flow parameters and exhaust noise is shown in figure 7.

In addition to the exhaust noise tests, total noise tests (muffler condition 5 in table 1) were performed in room B for comparison purposes. One-third-octave measurements for the total noise tests are shown in figures 8-9 for inlet pressures of 100 and 75 psig. A photograph of this test setup, located in room B, is shown in figure 10. To obtain a more detailed spectrum, all of the aforementioned tests were complemented with noise measurements in which a 10-Hz filter was used; some of the tests are shown in figures 11-12.

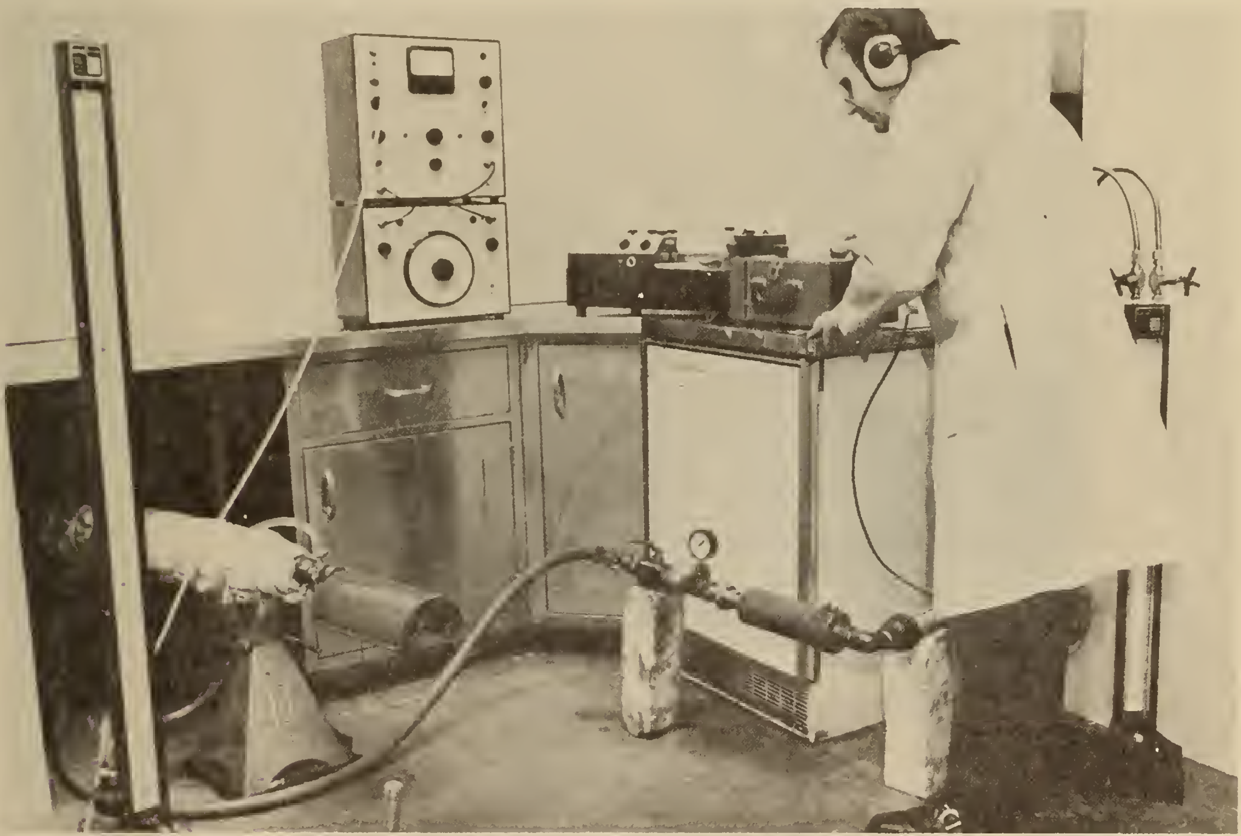


FIGURE 7. - Test setup in room A for exhaust noise tests.

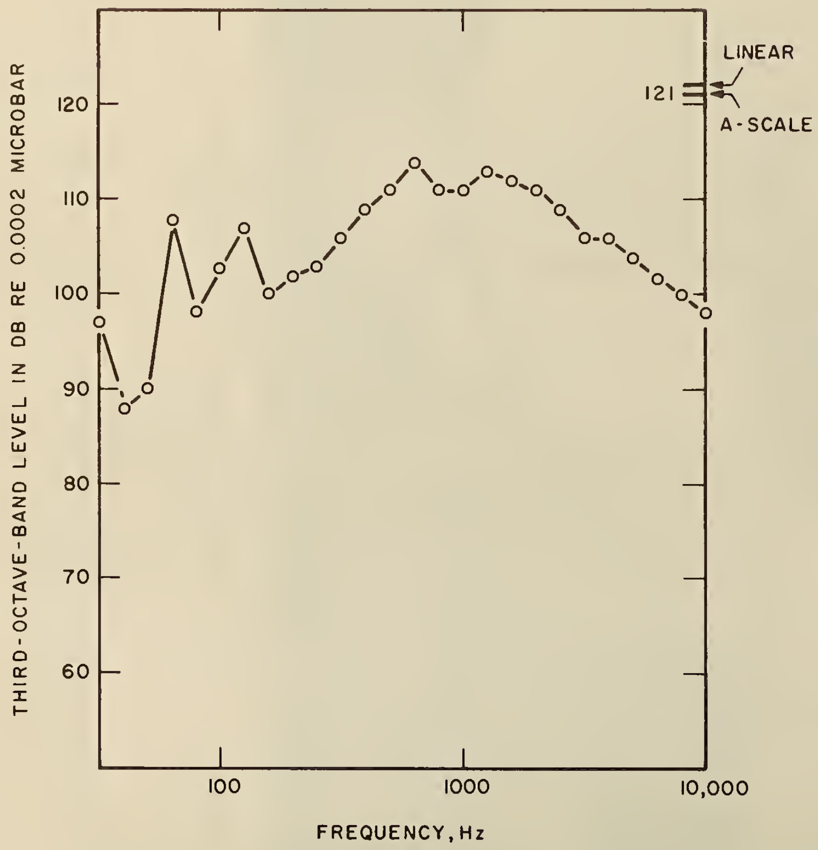


FIGURE 8. - Total noise (muffler condition 5), 100 psig.

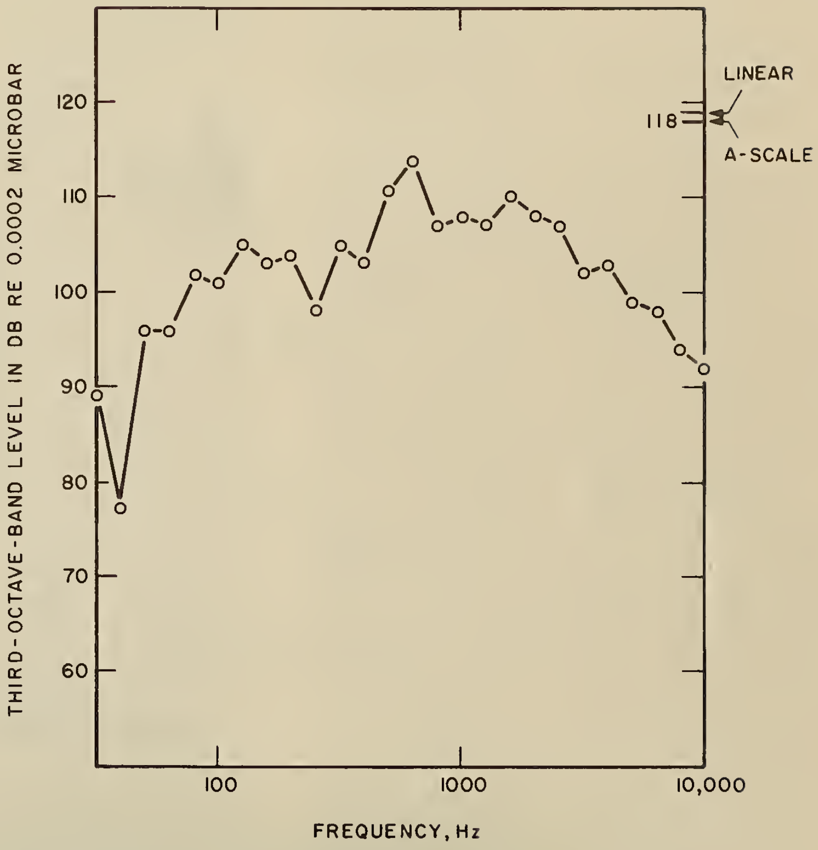
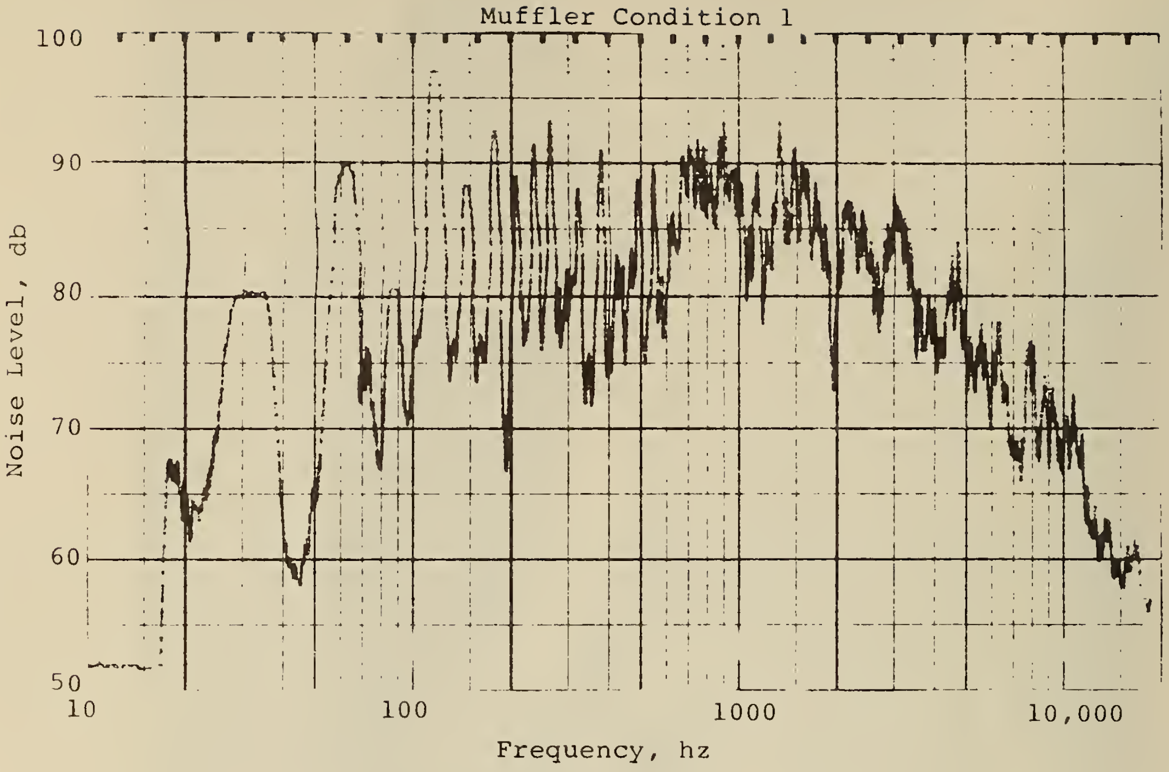


FIGURE 9. - Total noise (muffler condition 5), 75 psig.

FIGURE 10. - Test setup in room B for total noise tests.



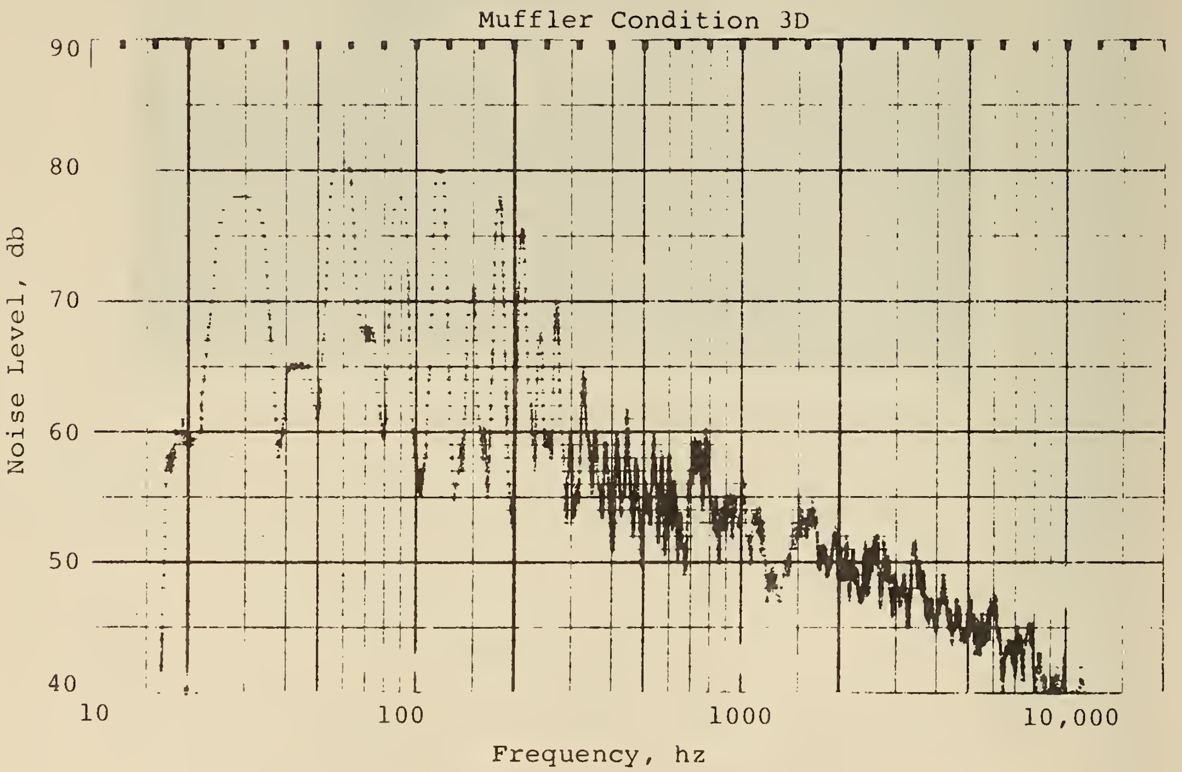
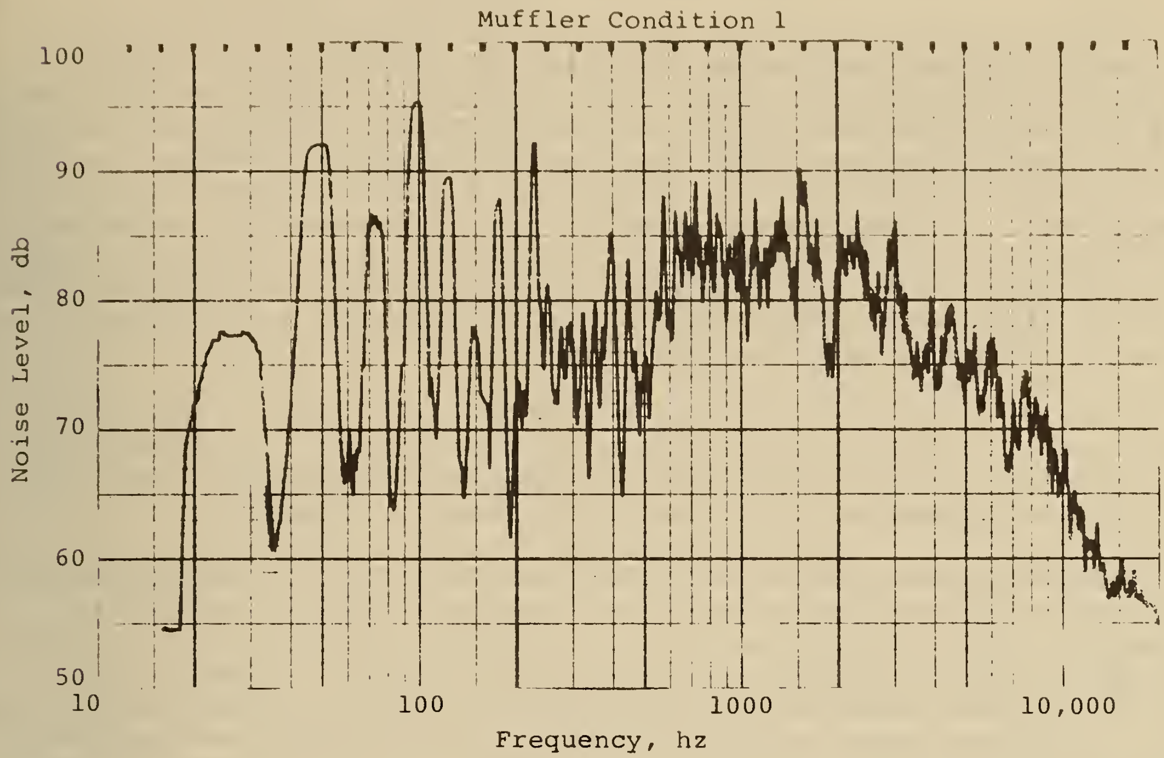


FIGURE 11. - Exhaust noise using 10-Hz filters, 100 psig.



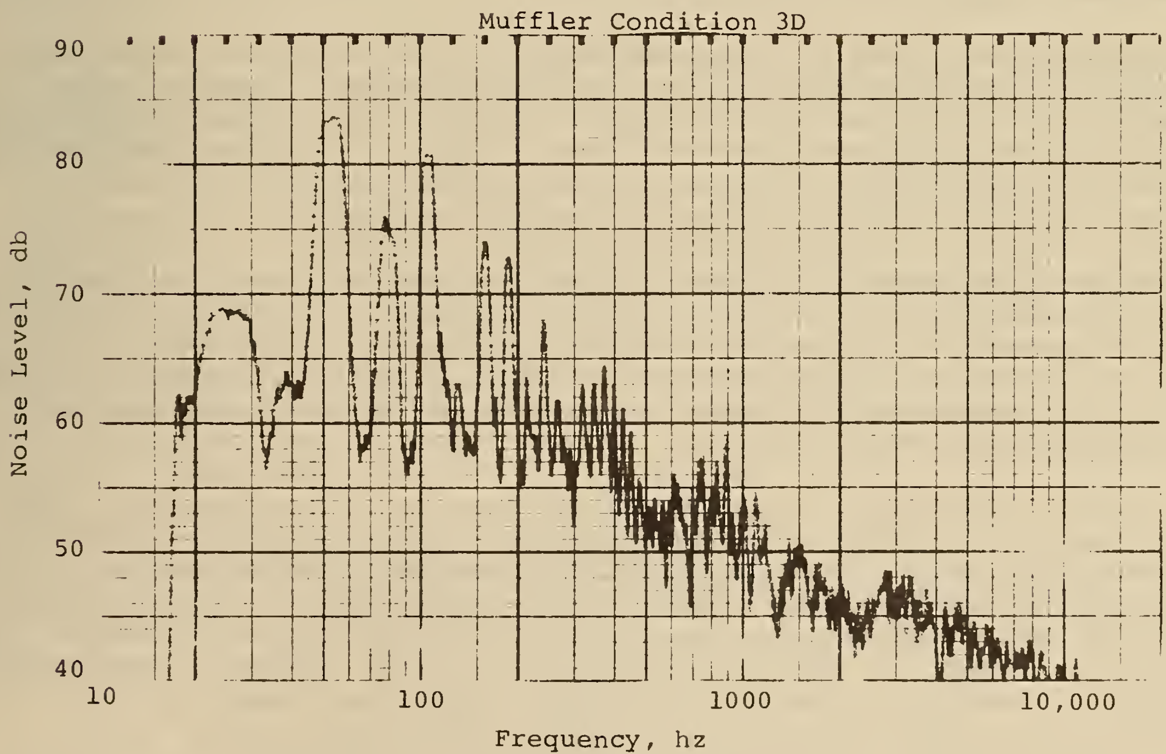


FIGURE 12. - Exhaust noise using 10-Hz filters, 75 psig.

EXHAUST AIR NOISE LABORATORY TEST RESULTS

Results of tests for muffler condition 1 (no muffler) illustrate the base condition for all laboratory tests evaluating the muffler designs for the reduction of exhaust-air noise and back pressure. In this base condition, two inlet operating pressures (P_2 = 100 and 75 psig) were used. The difference in the exhaust noise level resulting from these two pressures was about 3 dbA, as shown in table 1; the highest value of 113 dbA resulted from the higher pressure. Throughout the remaining tests, the noise-level difference ranged from zero to 4 dbA for the two operating pressures. Therefore, because 75 psig is probably the more realistic value achieved in a drilling operation, discussion of the test results will be largely restricted to the values obtained at this operating inlet pressure.

Volume flow rates (Q) for the stoper drill used in these tests varied with pressure. The lower inlet pressure, P_2, resulted in a flow rate of from 1 to 9 ft^3/min less than that for the higher pressure; absolute values ranging from 90 to 102 ft^3/min were recorded for the lower pressure.

In all the tests, the two major items of concern for the various muffler configurations were the air exhaust noise (expressed in dbA) and the back pressure, M_2. Back pressure is directly related to drilling rate; the higher the back pressure, the lower the drilling rate. The use of muffler 1 (fig. 1), compared with tests without a muffler, reduced the exhaust noise from 110 to 84 dbA for a total reduction of 26 dbA. This muffler also indicated a back pressure of 0.4 psi at the lower P_2 value. These results are recorded as muffler condition 2 in table 1.

Muffler 2 was designed to improve muffler 1 and to examine the tradeoffs between acoustic performance and fluid-flow pressure drop. Muffler conditions 3A, 3B, 3C, 3D, and 3E for muffler 2 represent the various configuration changes that were performed on the original muffler 1. Muffler condition 3A, representing the addition of another neoprene foam section to the first chamber of muffler 1 for more sound absorption, demonstrates the expected 1- to 4-dbA increase in noise attenuation over that of muffler 1; however, the back pressure of muffler 2 increased accordingly to 1.00 psi at the lower P_2 value. Blocking the second chamber (muffler condition 3B) resulted in negligible noise reduction over muffler condition 3A, the overall dbA value (at P_2 of 75 psig) remaining at 80 for both conditions--1.00 psi for condition 3A and 0.89 psi for condition 3B. Similar conclusions can be made for results with the higher P_2 pressure of 100 psig.

Muffler condition 3C (compared with 3A) demonstrates a significant tradeoff in the test values for this muffler and shows the significance of the use of disks on the outlet tubes of muffler 2. Noise reduction with disks (condition 3A) was 5 to 6 dbA superior to the noise reduction without disks (condition 3C); however, back pressures with the disks were significantly higher than without the disks--an increase of 0.93 and 1.41 psi. The effect of disks is therefore evident; they provide a significant amount of noise reduction in a small space but give a higher back pressure, which leads to lower drilling rates. The actual drilling rate is dependent on the type of

of rock (the drilling medium) and the type of drill system (including the operating thermodynamic parameters).

Muffler conditions 3D and 3E represent a new second-chamber design for the kidney-shaped muffler--with disks for condition 3D and without disks for condition 3E. With disks, the new design 3D indicates a reduction in noise level of 3 to 4 dbA (compared with condition 3A) with about the same back pressure. Without disks, as indicated by the test results for condition 3E, the noise values increased about 7 dbA over condition 3D, and the back pressure decreased in the expected manner to 0.19 and 0.29 psi. Noise-control effectiveness for design 3D is shown in figures 4-5--for inlet pressures of 100 and 75 psig, there were dbA reductions of 34 and 33, respectively, compared with the dbA values for tests without a muffler (condition 1). These values represent the highest attenuation of all the mufflers tested.

Muffler conditions 4A and 4B represent designs in which the second chamber was completely eliminated. With disks, the test results for condition 4A were, as expected, close to those for 3B. However, the change from disks to no disks (from 4A to 4B) resulted in a greater increase in noise level than did comparable changes from conditions 3A to 3C and from 3D to 3E.

The total noise (both from exhaust air and mechanical radiation from the drill cylinder) is represented by condition 5. These values (121 and 118 dba) were used as controls for the exhaust air noise tests discussed previously; detailed 1/3-octave spectrums for the two pressure conditions are shown in figures 8-9.

To obtain a more detailed record of the exhaust noise, noise spectrums were taken by using a 10-Hz filter. Two representative spectrums showing the peaks on this fixed bandwidth are shown in figures 11-12 for 100- and 75-psig conditions.

EXHAUST AIR NOISE FIELD TEST CONDITIONS

Field tests were performed on April 30, 1974, on several kidney-shaped mufflers attached to one RP38E stoper drill. The tests were conducted in Robena No. 3 mine of U.S. Steel in a three-sided enclosure, approximately 25 feet long by 14 feet wide by 8 feet high, and identified as near "McGeever's Switch." The rock drilled was solid sandrock and was drilled to a total penetration of 5 feet per hole. Table 3 presents the summary of results for these tests.

Previous field testing was performed on March 14, 1973, at the lower splint (Section B-47) of Lynch No. 32 mine of U.S. Steel. A summary of results for these previous tests is also shown in table 3. These tests involved the drilling of 24 holes in solid sandrock, in each case to a minimum depth of 4 feet.

TABLE 3. - Summary of preliminary results for field tests on mufflers

Muffler condition	Drilling time average,[1] seconds		Back pressure,[2] psi	Operating air pressure, psig	Average overall noise level,[3] dbA	
	Starter drill	Both drills			Starter drill	Second drill
ROBENA MINE NO. 3--APRIL 30, 1974 (COMPLETED ON MAY 2, 1974)						
1. No muffler...........	129	199 (1.5 ft/min)	-	72-86	116	116
2. 3E....................	136	195 (1.5 ft/min)	1.0-2.0	72-86	110	110
3. 3C....................	144	212 (1.4 ft/min)	1.0-2.5	72-86	109	109
4. 4B....................	137	196 (1.5 ft/min)	.5-1.0	72-86	110	109
LYNCH MINE NO. 32--MARCH 14, 1973						
5. No muffler...........	-	(2.6 ft/min)	-	97	121	-
6. 3C....................	-	(2.7 ft/min)	-	97	116	-

[1]For each muffler condition, there were 5 holes drilled using 2 drill rods: The starter drill (approximately 43 inches long) to penetrate approximately 38 inches; the second drill (approximately 78 inches long) to penetrate to the final length of 5 feet. A new starter bit was used for each muffler condition or each group of 5 holes; a new second bit was used for each hole.

[2]Back pressure was measured in a 1-inch-ID hose before the muffler by a mechanical gage.

[3]All measurements were taken 5-1/2 feet above ground with microphone in the vertical position and about 1 foot from the operator's ear.

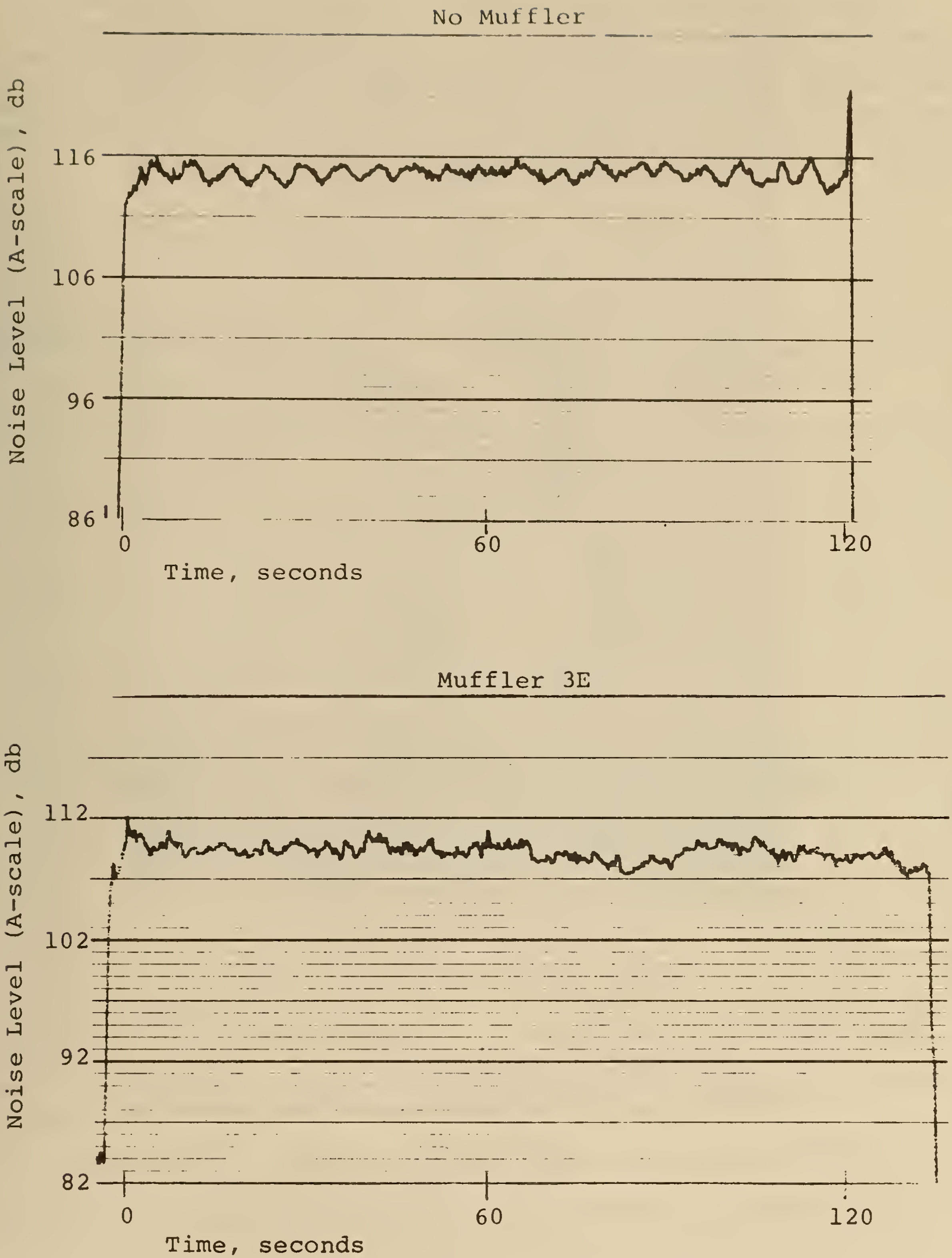


FIGURE 13. - A-scale readings for starter drill at Robena mine.

Frequency modulation tape recordings of the noise at the Robena mine was taken by using the B&K condenser microphone type 4131, microphone amplifier type 2603, and an instrumentation tape recorder type 7001. The recordings were analyzed and converted to graphical form by using the band-pass filter set type 1612 and the graphic sound level recorder 2305. Figures 13-14 show representative A-scale readings taken during the testing. A photograph showing the test setup used in the mine is shown in figure 15.

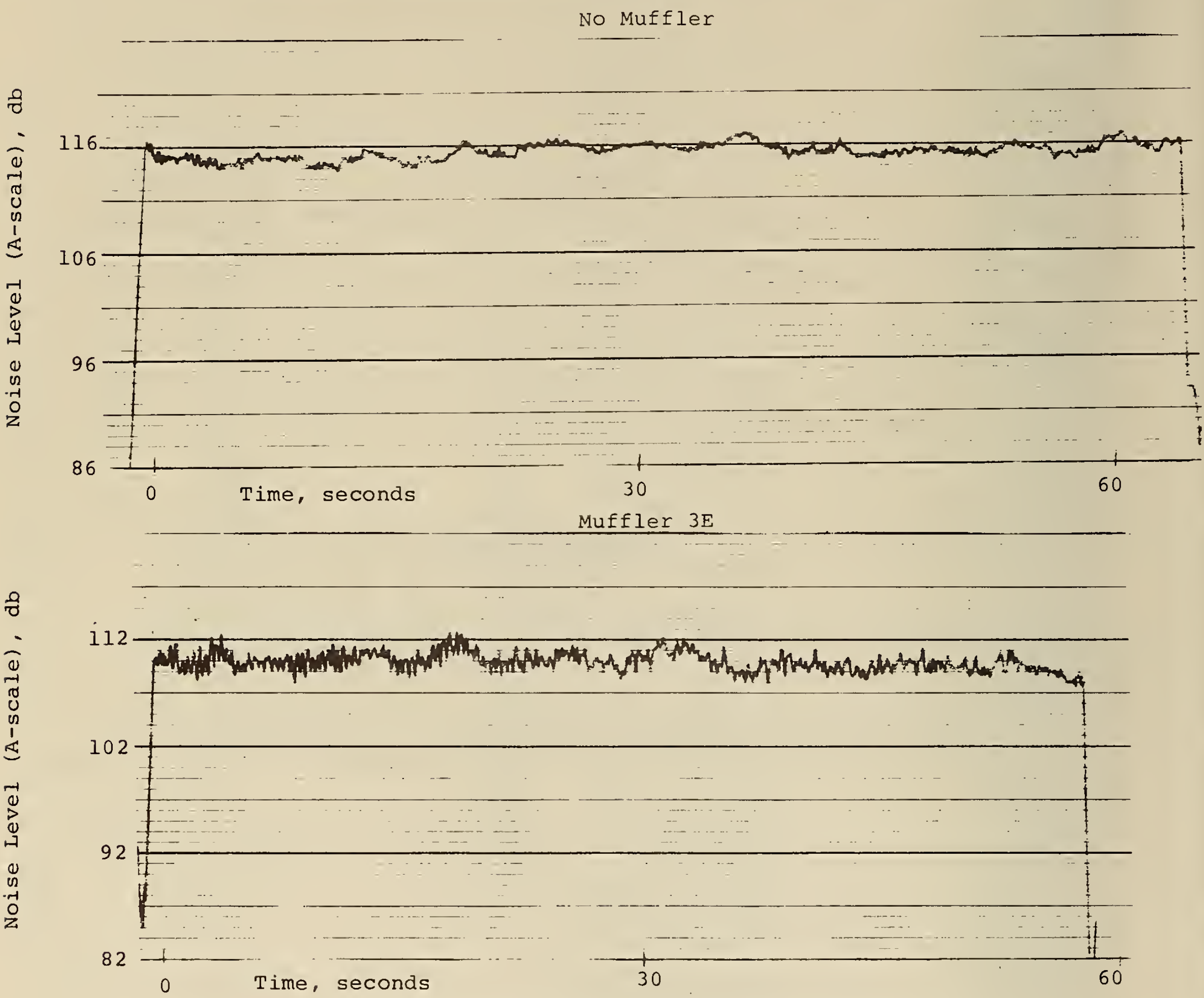


FIGURE 14. - A-scale readings for second drill at Robena mine.

FIGURE 15. - Test setup in Robena mine.

EXHAUST AIR NOISE FIELD TEST RESULTS

Reverberation-time measurements of the mine tests were recorded. Times recorded for 1/3-octave bands about the center frequencies are shown in table 4. From the results of these field tests, shown in table 3, the following general conclusions were established for both mines:

1. The mufflers attenuated the overall noise level by 6 to 7 dbA.

2. The drilling rate was essentially the same with and without the mufflers.

3. No icing problems occurred with the mufflers.

TABLE 4. - Reverberation times at Robena mine test site

Center frequency, Hz	Reverberation time, seconds	Center frequency, Hz	Reverberation time, seconds
31.5	1.063	2,000.0	0.760
63.0	.578	4,000.0	.760
125.0	.750	8,000.0	.760
250.0	.750	A-scale..........	.770
500.0	.770	Linear...........	.780
1,000.0	.770		

Representative A-scale readings are shown in figures 13-14 for the case of the starter drill and the second drill, respectively. In both figures, muffler condition 3E is compared with muffler condition 1 (no muffler).

To characterize acoustically the mine site at Robena, reverberation times were determined after analysis of the data from the tape recorder. As shown in table 4, these times were almost all in the neighborhood of 0.75 to 0.78 second. These times are a measure of how much of the total noise is reverberation sound reflected from the surrounding walls as compared to the direct sound from the noise source. The laboratory rooms (A and B) at U.S. Steel Research are close to these values.

MECHANICAL NOISE RADIATION LABORATORY TESTS

In addition to the noise from the air exhaust, the source of greatest noise in the stoper drill, the mechanical noise emanating from the drill surface should be controlled. To attempt this control, several acoustic enclosures systems were designed, constructed, and tested in the laboratory for their effectiveness in controlling mechanical noise. Tests were conducted to determine the acoustic effectiveness of this initial system. The general test arrangement is shown in figure 2. The muffler used for the exhaust air during these tests was the kidney-shaped muffler 3E; the muffler was attached to the upper part of the air leg. The drill inlet pressure was maintained at 75 and 100 psig for each test condition.

Measurements for different conditions of the drill are summarized in tables 5, 6, and 7 for enclosure 1, enclosure 2, and enclosure 3, respectively. Representative 1/3-octave-band measurements are plotted in figure 16 for one acoustic enclosure.

ACOUSTIC ENCLOSURE 1

Design

An enclosure system for the attenuation of mechanical noise emanating from the drill surface (designated as enclosure system 1) has been designed, constructed, and tested in the laboratory. This system encloses, and could incorporate, the kidney-shaped mufflers used for the attenuation of exhaust noise. The enclosure for mechanical noise is oval-shaped in cross section (approximately 13 inches in diameter along the major axis and 10-1/2 inches in

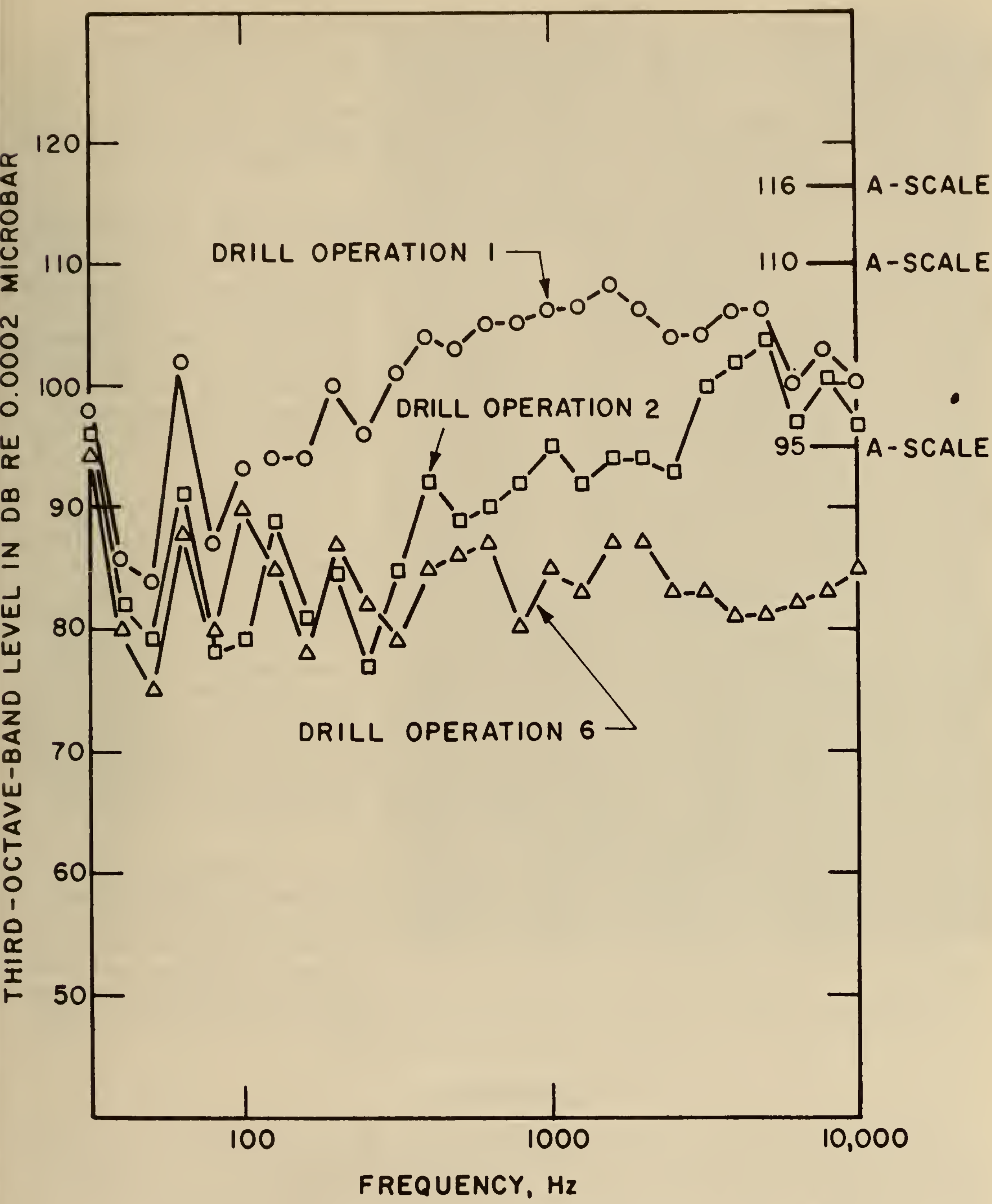


FIGURE 16. - Noise spectrum for acoustic enclosure tests, 100 psig.

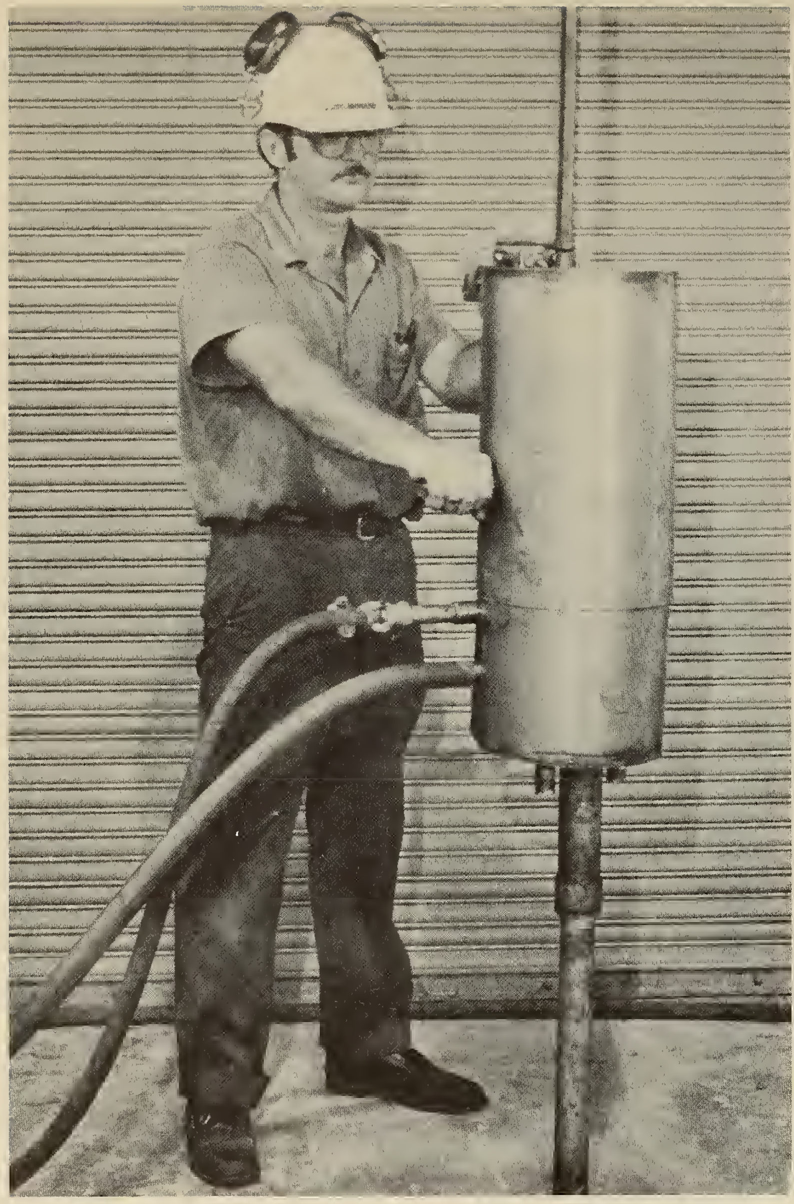


FIGURE 17. - Acoustic enclosure 1 for mechanical noise.

diameter along the minor axis) and 26 inches long. Figure 17 shows this system on the drill. The total weight of this enclosure is 39 pounds.

The top of the enclosure consists of an external 1/8-inch-thick sheath made of carbon steel, a layer of 1/4-inch-thick rigid neoprene (0.05 lbm/in^3 density), and a layer of 2-inch-thick neoprene foam (4 lbm/ft^3 density). An opening is provided in the top for the anvil block.

An external 16-gage (0.0625-inch-thick) sheath made of carbon steel, a layer of 1/4-inch-thick rigid neoprene, and a layer of 1-inch-thick neoprene foam comprise the side of the enclosure. Openings are provided in the side for the operating handle, air-inlet connection, dust-ejector connection, and throttle-valve handle.

The bottom of the enclosure consists of an external 1/8-inch-thick sheath made of carbon steel, a layer of 1/4-inch-thick rigid neoprene, and a layer of 2-inch-thick neoprene foam. Openings are provided in the bottom for the air-feed leg and the air-exhaust line from the muffler.

Test Results

The overall results of the acoustic enclosure 1 tests, with different operating conditions (under no load), are presented in table 5. For drill operation without either a muffler or an acoustic barrier (drill operation 1), the total drill noise levels are 112 and 116 dbA for 75- and 100-psig pressure pressures, respectively. With a muffler (operation 2), these levels were reduced to 106 and 110 dbA.

TABLE 5. - Summary of laboratory noise control tests for acoustic enclosure 1

Drill operation	Muffler	Acoustic barrier	Drill rod inserted	Air pressure, psig	Noise level,[1] dbA	Microphone room position	Figure reference
1. Total noise with no muffler and acoustic barrier.	None	No	No	75	112	B	16
				100	116	B	-
2. Total noise with muffler.	3E	No	No	75	106	B	-
				100	110	B	16
3. Exhaust noise with exhaust air piped into room A by two 1-inch-ID hoses (10 feet long).	3E	Yes	No	75	85	A	-
				100	86	A	-
4. Chuck exhaust noise with chuck air piped into room A by two 1/2-inch-ID hoses (10 feet long).	3E	Yes	No	75	66	A	-
				100	68	A	-
5. Total noise with muffler and acoustic barrier.	3E	Yes	No	75	93	B	-
				100	95	B	-
6. Total noise with muffler and acoustic barrier and no dust air suction.	3E	Yes	Yes	75	93	B	-
				100	95	B	16
7. Mechanical noise with exhaust air piped into room A.	3E	Yes	No	75	92	B	-
				100	94	B	-
8. Drill not operating--with dust air suction.	3E	Yes	No	75	91	B	-
				100	94	B	-
9. Drill not operating--without dust air suction.	3E	Yes	Yes	75	83	B	-
				100	86	B	-
10. Ambient...............	-	-	-	-	52	B	-

[1]All microphone measurements were taken 1 meter from drill exhaust with microphone in vertical position about 1 meter above the ground.

Operations 3-7 show the acoustic-attenuation effects of operating the drill with both a muffler and an acoustic barrier. Operation 3 shows the effectiveness of the muffler, which reduced the exhaust noise to 85 and 86 dbA. Operation 4 shows the magnitude of another exhaust-air noise, which emanates from the chuck; these values were relatively small at levels of 66 and 68 dbA. The total noise levels with both a muffler and an acoustic barrier (operation 5) were 93 and 95 dbA, which represents reductions of 13 and 15 dbA obtained by using the barrier (compared with values obtained by using the muffler alone). Operation 6 shows the negligible effect on total noise by eliminating the noise emanating from the dust air suction.

Operations 8-9 show the lower limit noises associated with a drill not operating but pressurized. With the dust-air-suction noise (operation 8), levels of 91 and 94 dbA were obtained. Without the dust-air-suction noise (operation 9), levels of 83 and 86 dbA were obtained. The ambient-noise level in room B with the drill not pressurized was 52 dbA (operation 10).

Figure 16 shows the progression of reduction of noise level at 100-psig operating pressure. The dbA decreased to 110 with a muffler and then to 95 with both a muffler and an acoustic enclosure.

ACOUSTIC ENCLOSURE 2

Design

An additional system for the attenuation of mechanical noise (designated as enclosure system 2) has also been designed, constructed, and tested. This enclosure system is oval-shaped in cross section (approximately 15 inches in diameter along the major axis and 12-1/2 inches in diameter along the minor axis) and 26 inches long. It is similar in shape to enclosure 1.

The top of the enclosure consists of an external 1/8-inch-thick sheath made of carbon steel and a layer of 2-inch-thick neoprene foam (4 lbm/ft^3 density). An opening is provided in the top for the anvil block.

A constrained layer consisting of a sheath of 20-gage carbon steel, 0.030-inch-thick USS NEXUS P-1003 material, and 20-gage carbon steel; and a layer of 2-inch-thick neoprene foam comprise the side of the enclosure. Openings are provided in the side for the operating handle, air-inlet connection, dust-ejector connection, and throttle-valve handle.

The material for the bottom of the enclosure is the same as that for the top. Openings are provided in the bottom for the air-feed leg and the air-exhaust line from the muffler.

The total weight of this enclosure is 42 pounds. Tests were conducted to determine the effectiveness of this system. The general test arrangement was similar to that for enclosure 1.

Test Results

The overall results of the acoustic enclosure 2 tests with different inlet operating pressures of 75 and 100 psig (under no-load conditions), are shown in table 6. For drill operation 1, the noise condition of an unabated drill, total noise levels of 116 and 121 dbA were obtained for pressures of 75 and 100 psig, respectively. With the addition of a muffler, these levels were reduced to the mechanical noise levels of 101 and 103 dbA (drill operation 2). With the addition of acoustic enclosure 2, the noise levels were further reduced to 93 and 95 dbA (operation 4). The effect of dust air suction on this condition was negligible (operation 5).

TABLE 6. - Summary of laboratory noise control tests for acoustic enclosure 2

Drill operation	Muffler	Acoustic barrier	Drill rod inserted	Air pressure, psig	Noise level,[1] dbA	Microphone room position
1. Total noise with no muffler and acoustic enclosure.	None	No	No	75	116	B
				100	121	B
2. Total noise with muffler.	3D	No	No	75	101	B
				100	103	B
3. Total noise with muffler and barrier.	3D	Yes	No	75	93	B
				100	95	B
4. Total noise with muffler and barrier.	3D	Yes	Yes	75	93	B
				100	95	B
5. Mechanical noise with exhaust air piped away.	3D	Yes	No	75	94	B
				100	96	B
6. Mechanical noise with exhaust air piped away.	3D	Yes	Yes	75	92	B
				100	94	B

[1]All microphone measurements were taken 1 meter from drill exhaust with microphone in vertical position about 1 meter above the ground

FIGURE 18. - Acoustic enclosure 3.

Mechanical noise only was measured by piping the exhaust air into another room, acoustically isolated from the room in which the drill was placed. With dust air noise, the mechanical-noise values were measured at 94 and 96 dbA (operation 5). With the elimination of dust air noise, these values dropped 2 dbA to 92 and 94 dbA (operation 6).

ACOUSTIC ENCLOSURE 3

Design

Acoustic enclosures 1 and 2 were analyzed, and after a progression of development, an acoustic enclosure 3 was designed and constructed. This enclosure has the same external dimensions, openings, and neoprene foam as acoustic enclosure 1; however, the top and bottom of the sheath are 16-gage carbon steel sheet and the sides are 20-gage carbon steel sheet. This enclosure is shown in figure 18. The handle for operator has been incorporated into the shell of the enclosure.

Details of the lower and upper half of the enclosure sheet metal construction are shown in figures 19-20, respectively. The total weight of this enclosure is about 20 pounds.

Test Results

Tests were conducted to determine the acoustic effectiveness of the third acoustic enclosure in the laboratory in the same arrangement as the first two enclosures. The overall results with this lighter system are shown in table 7 and indicate the noise levels are in the range from 90 to 92 dbA with the enclosure (and the muffler) attached.

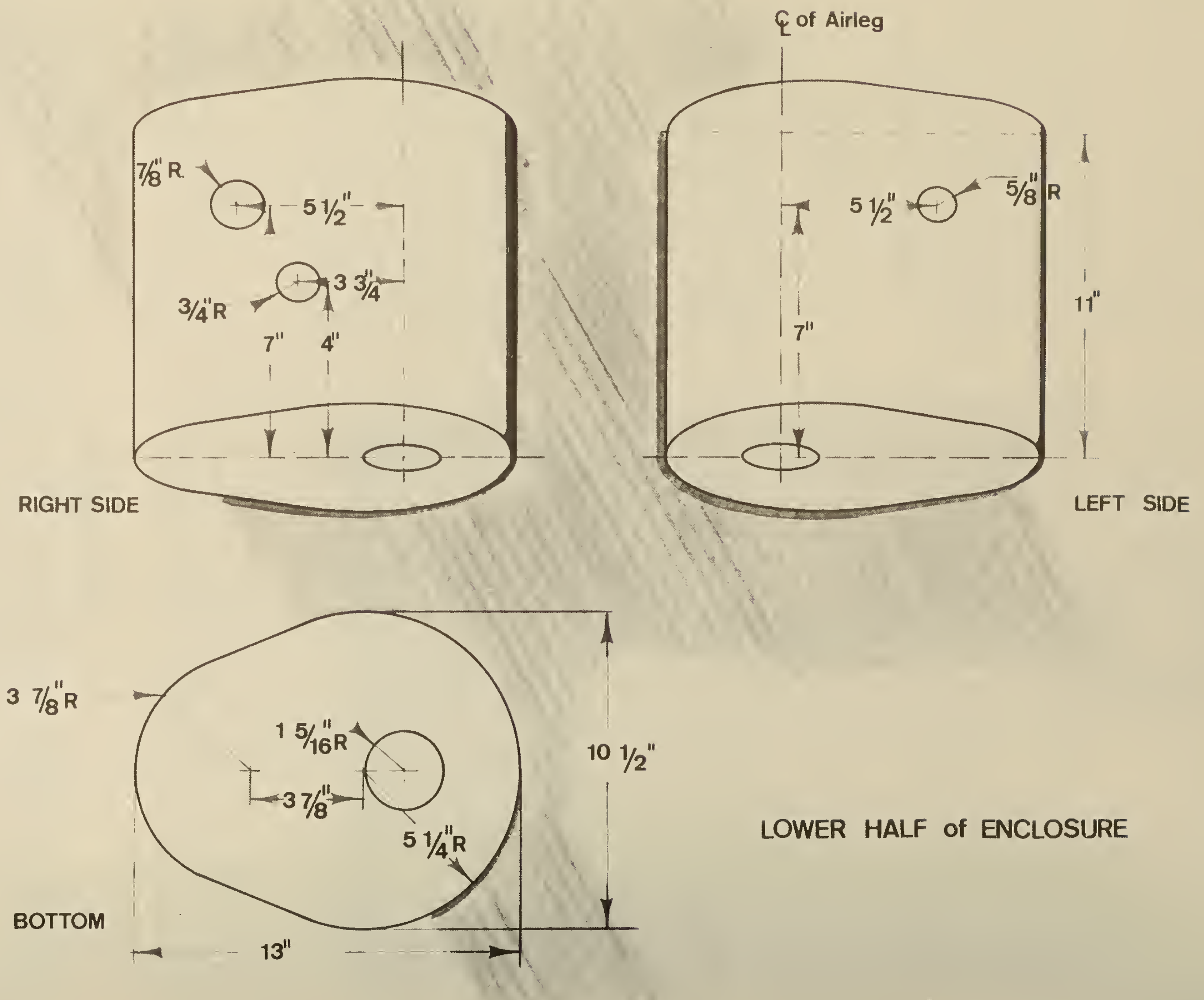


FIGURE 19. - Lower half of acoustic enclosure 3.

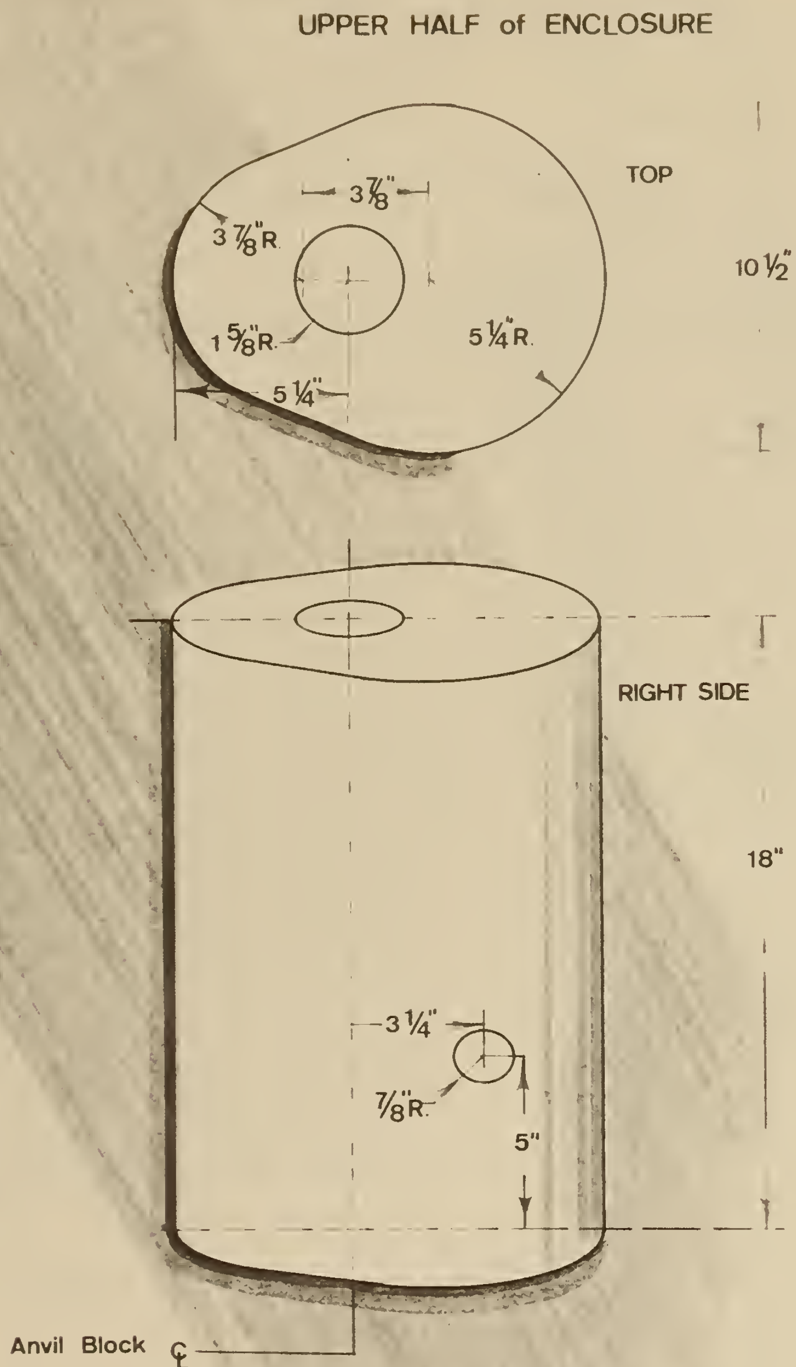


FIGURE 20. - Upper half of acoustic enclosure 3.

TABLE 7. - Summary of noise control tests for acoustic enclosure 3

Drill operation	Muffler	Acoustic barrier	Drill rod inserted	Air pressure, psig	Noise level,[1] dbA	Microphone room position
1. Mechanical noise with exhaust air piped into room A.	3D	Yes	Yes	75	90	B
				100	92	B
2. Total noise with muffler and acoustic barrier.	3D	Yes	Yes	75	90	B
				100	92	B

[1]All microphone measurements were taken 1 meter from drill and 1 meter aboveground with microphone in vertical position.

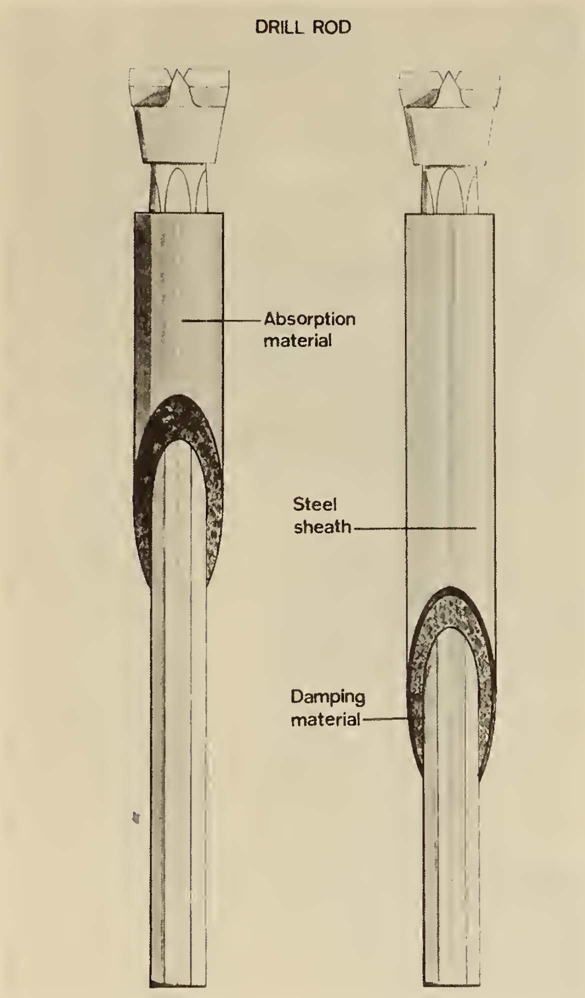


FIGURE 21. - Control units for percussion noise of drill rods.

PERCUSSION NOISE LABORATORY TESTS

Acoustic absorptive units that wrap around the drill rod and attenuate the rod vibration and percussion noise have been designed and constructed. Two types of control units--absorptive elastomer foams and damping sheaths--have been developed. The damping sheath concept has been tested in the laboratory for its vibration damping effectiveness using transfer function analyzing equipment. A schematic of the two types of systems is shown in figure 21. Figure 22 indicates the details of the systems designed and constructed. These units were designed to attenuate the percussion noise, which occurs when the piston strikes the anvil block which holds the drill rod, as shown in figure 23. Stages A and B indicate the piston in different positions during its operating cycle. Although the design and testing were restricted to a specific drill size, the basic design information is applicable to drills of all sizes and can be used to scale other designs.

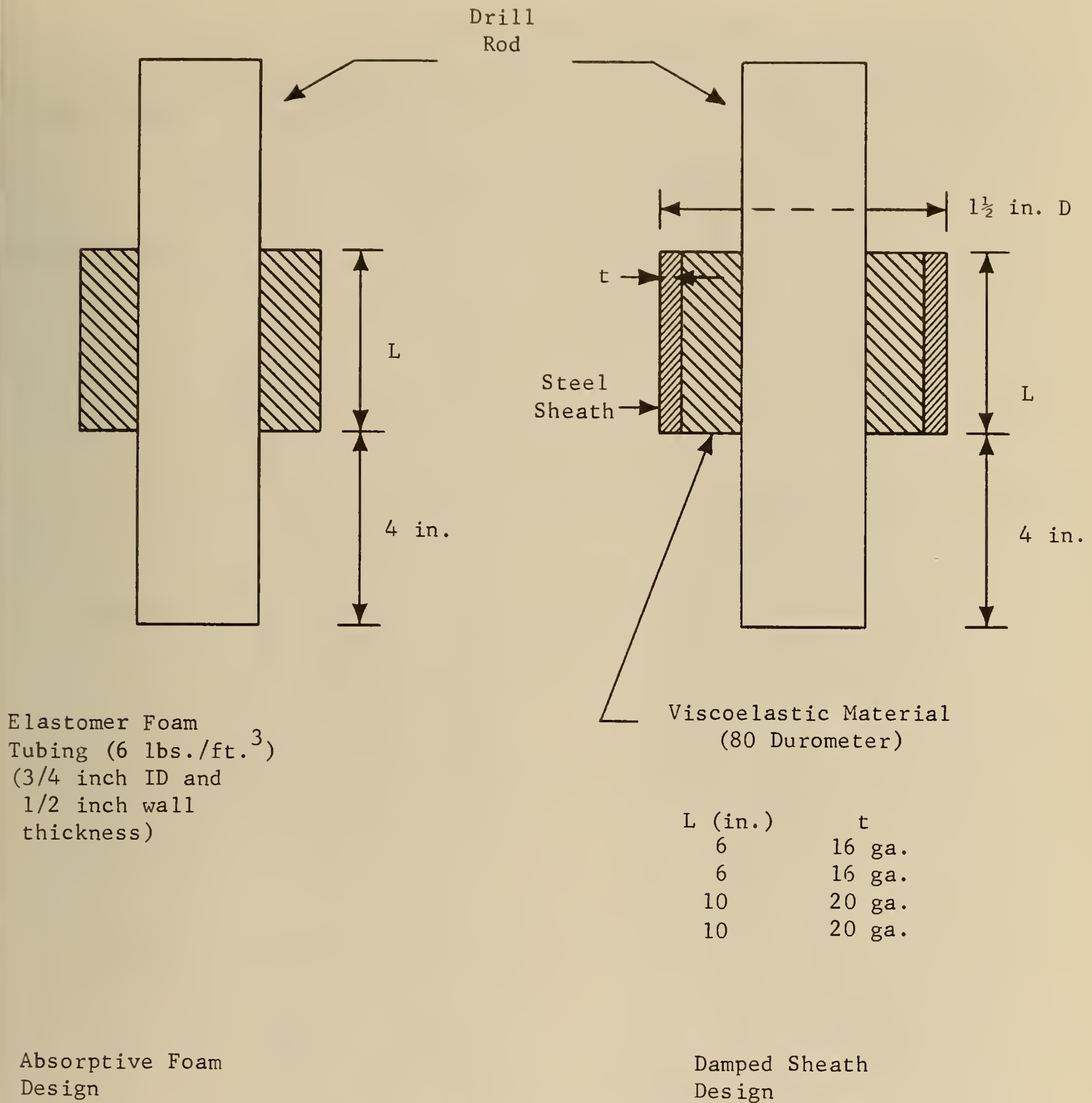


FIGURE 22. - Details of control units for percussion noise.

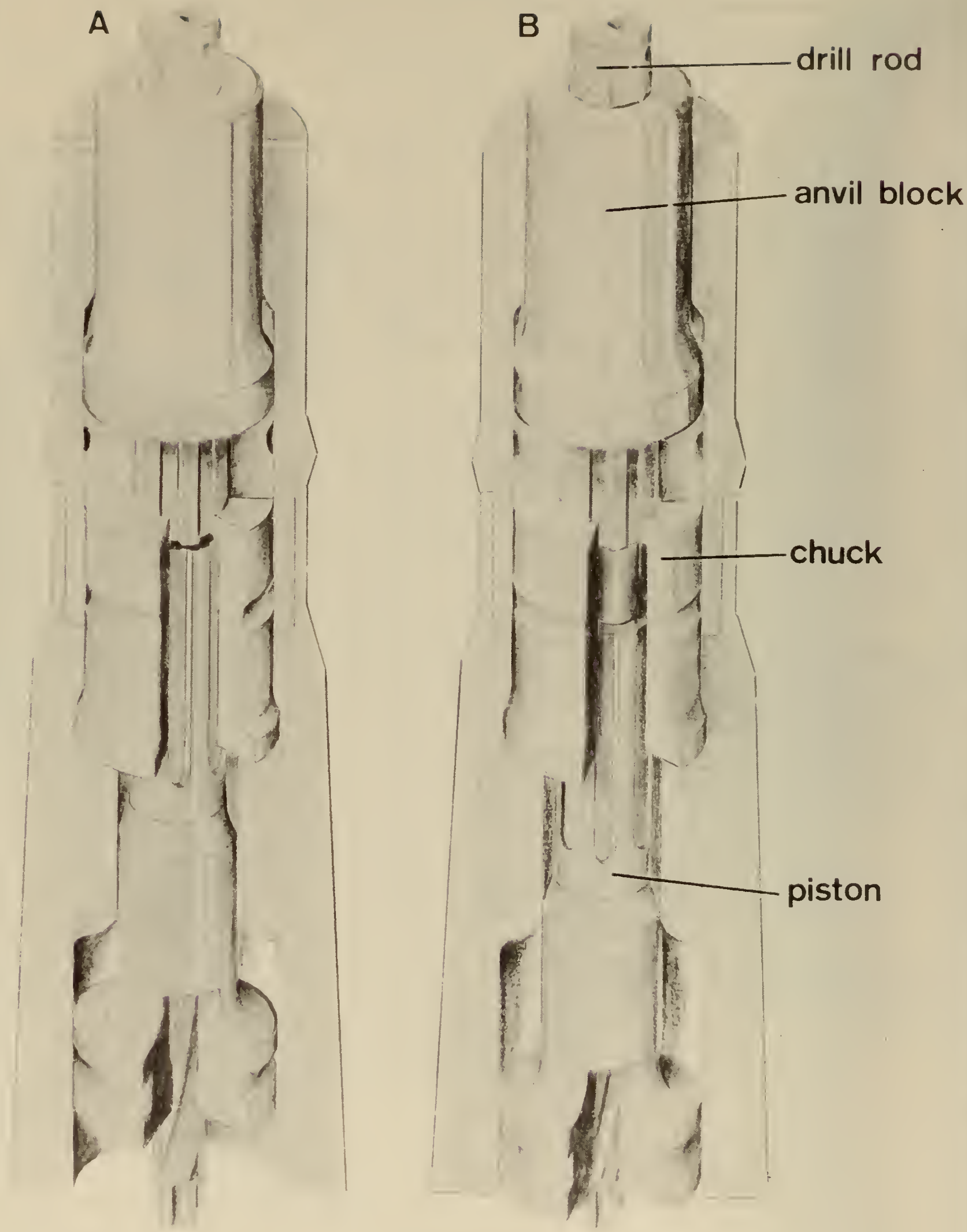


FIGURE 23. - Basic moving parts of drill.

NOISE CONTROL SYSTEM FIELD TESTS

Field tests were conducted at the experimental research mine of the Federal Bureau of Mines at Bruceton, Pa. The noise control systems employed on the drill were--

Noise	Noise control device
Exhaust............	6 inch kidney-shaped muffler (4B).
	10 inch kidney-shaped muffler (3E).
Mechanical.........	Acoustic enclosure 3.
Percussion.........	Absorptive foam on drill rod.
	Damped sheath on drill rod.

Representative systems for control of the percussion noise are shown in figure 24. A schematic of the muffler and acoustic barrier system is shown in figure 25. The two mufflers used are shown in figure 26.

Drilling tests were conducted at an air inlet pressure of about 70 psig and to penetrations of 30 inches. A summary of noise results are shown in the following tabulation:

Muffler, inches	Drill rod systems	Noise level, dbA
6	Absorptive foam..............	96-99
	Damped sheath................	94-96
10	Absorptive foam..............	90-95
	Damped sheath................	88-90

Pictures of the setup in the mine are shown in figures 27-28.

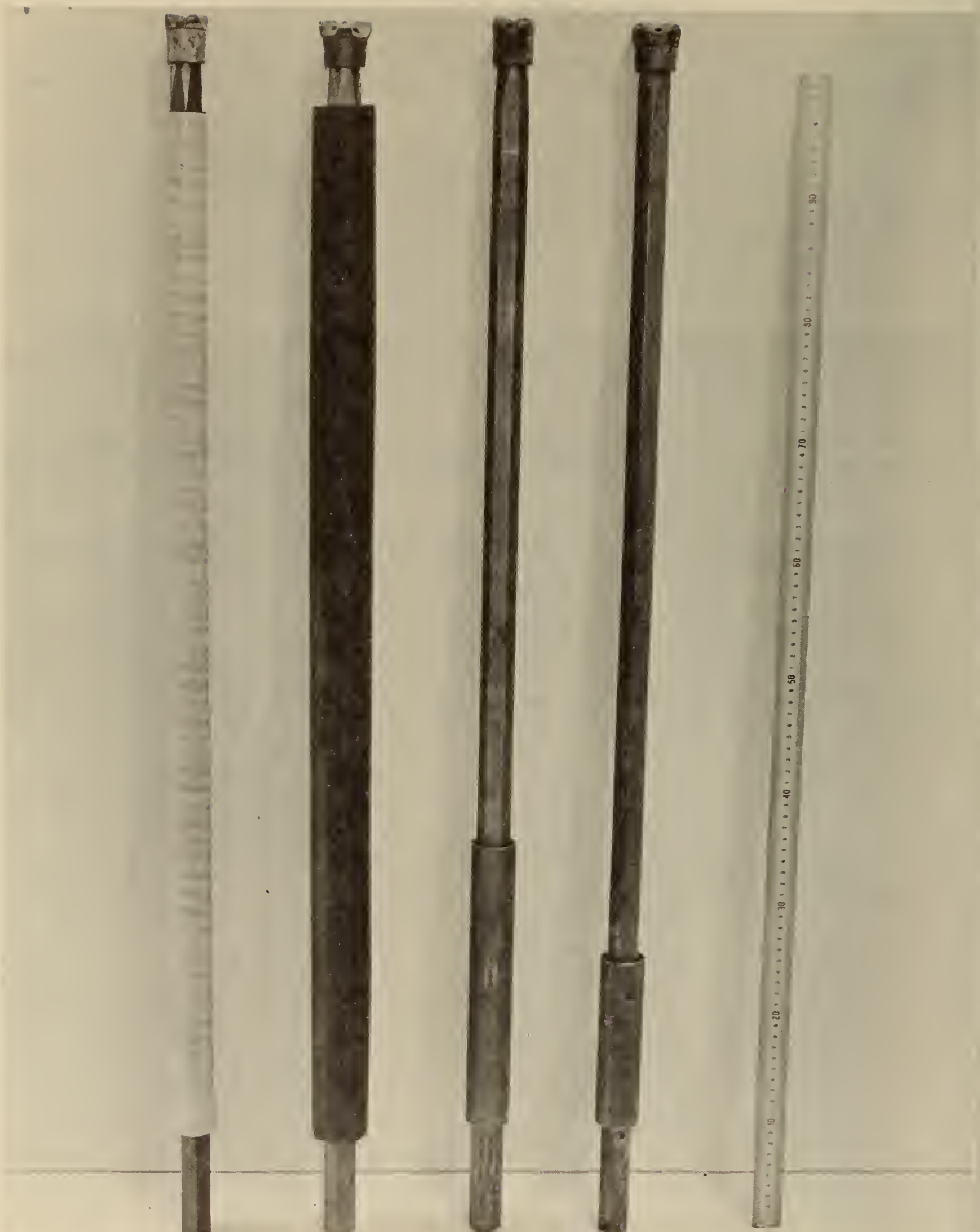


FIGURE 24. - Systems for control of percussion noise.

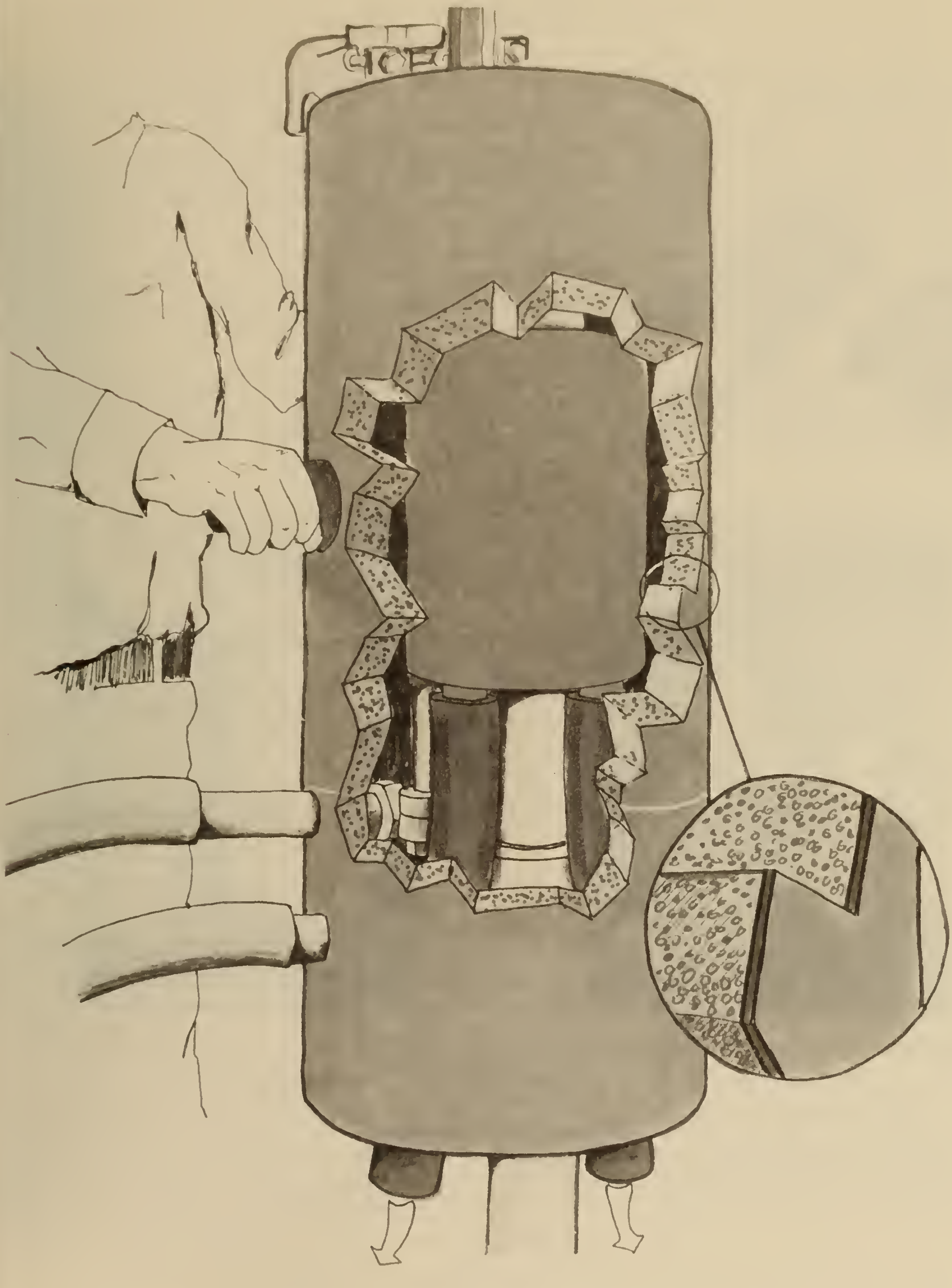


FIGURE 25. - Muffler and acoustic enclosure system.

FIGURE 26. - Mufflers used in field tests.

FIGURE 27. - Overall test setup in mine.

FIGURE 28. - Details of noise control setup in mine.

CONCLUSIONS

This paper extends the previous work on pneumatic drill noise control to other kidney-shaped mufflers of different internal-chamber configurations and lengths. Improved muffler configurations with greater exhaust noise attenuation have been developed. Laboratory tests of the new mufflers showed the effect of the design changes on back pressure (a measure of drilling efficiency) and noise reduction and demonstrated the possible tradeoffs between back pressure and noise reduction for the different designs. The best muffler for noise control had a 34-dbA attenuation for the exhaust air. The results of this work can be utilized as a basis for designing mufflers for other types of pneumatic drilling systems, including both different types of drills and drills of different air consumptions.

Field tests were performed at U.S. Steel's Robena No. 3 mine. In these tests, three specific mufflers were attached to drills, which were then used to drill into solid sandrock roof. The general conclusions of the testing were as follows:

1. The mufflers attenuated the overall noise level by 6 to 7 dbA.

2. The drilling rate was essentially the same with and without the mufflers.

3. No icing problems occurred with the mufflers.

Methods of controlling the mechanical noise radiating from the drill surface have also been developed. Oval-shaped acoustic enclosures were designed around the drill body to control this noise source. Both reflection and absorption acoustic techniques were employed in these designs, which consisted of steel sheet and elastomer foam. Laboratory tests of specific enclosures with mufflers enclosed indicated a total noise reduction into the region of 90 to 95 dbA.

Methods for controlling the mechanical noise resulting from the percussion of the drill have also been developed. Absorptive units that wrap around the drill rod have been developed for this control. Two types of units--absorptive elastomer foams and damping sheaths--are being used. The sheath design was aided by the use of transfer functions analyzing equipment in the laboratory.

Field tests were performed on the pneumatic drill with all three elements of the noise control system attached. Two mufflers, one enclosure, and several absorptive units for the drill rod were tested in specific combinations. Noise readings with the one 6-inch muffler indicated levels in the mid-90-dbA region. Noise readings with the other 10-inch muffler indicated levels in the low 90-dbA region.

FIELD STUDIES OF NOISE ABATEMENT SYSTEMS FOR PNEUMATIC ROCK DRILLS

by

Thomas G. Bobick[1]

ABSTRACT

Results from noise surveys conducted in underground coal mines indicate that the pneumatic stoping drills range from 120 to 114 dbA, with an approximate operating time of 3 to 4 hours. For the noise levels measured, the permitted time of operation would be from zero to 20 minutes.

Attenuation of this noise was initially attempted through the use of mufflers to quiet the exhaust noise. The use of commercially available and experimental mufflers have been effective in controlling the drill exhaust noise. Additional attempts to quiet these drills included work done by various research groups of the Bureau of Mines to control the amount of mechanical produced noise. These attempts have proved to be partially successful and point the way for future work.

INTRODUCTION

Extensive noise surveys conducted in underground coal mines have determined that the use of the pneumatic rock drill presents the major problem of compliance with the noise standard, Subpart F, Part 70, Title 30, Code of Federal Regulations. This section sets the allowable limits, which are the same as the present OSHA standards for noise exposure, for the coal mine worker.

The noise generated from stoping drills can be separated into three general areas: Exhaust noise, internal mechanical noise, and external mechanical noise. At the present time, the majority of the noise abatement attempts have been directed at the exhaust noise. Mufflers have been developed and are commercially available from several manufacturers.

The Noise Group, Pittsburgh Technical Support Center, Mining Enforcement and Safety Administration, has performed tests on three different exhaust mufflers. Testing has been conducted in controlled conditions both on the surface and in underground environments. A variety of operating parameters that were monitored include the operating air line pressure, back pressure caused by the muffler, and the time required to drill the hole. Acoustic data gathered include noise levels, total sound power, and noise source directionality. It should be noted that prior to any testing, all noise measuring equipment

[1] Mining engineer, Mining Enforcement and Safety Administration, Pittsburgh, Pa.

were acoustically calibrated with a 1,000-Hz tone of 114 db referenced to 20 $\mu N/M^2$.

EXHAUST MUFFLER EVALUATIONS

H. K. Porter (Mucka) Muffler

One of the first units to be tested was a muffler developed by H. K. Porter Co. This muffler, basically a dispersive type, reduces the exhaust stream noise by diffusing the flow among many small exit ports. It consists of a 1-inch-diameter pipe, 6 inches long, closed at one end and having small perforations drilled along its length. Several sections of hemispherical cups are mounted over the perforated pipe in complementary pairs forming spherical chambers as shown in figure 1. Because the mating surfaces of the complementary cups are not in contact, diffusion of the exhaust stream occurs through the chambers. The total weight of this system is approximately 3 to 4 pounds, and initial estimates of the cost are approximately $10.

Evaluation of this muffler was done in semifree field outdoors. In an effort to isolate the exhaust noise from the other noise sources of the drill, the exhaust stream was piped 30 feet from the drill through flexible tubing. To determine the noise reduction properties of the unit, acoustic measurements were made with and without the muffler installed. For both cases, the dbA sound levels, which were measured 1 meter from the exhaust end, were obtained; the total sound power emitted from the exhaust also was measured. A complete description of the sound power procedure is given in the appendix to this paper. The results obtained are summarized in the following tabulation:

	No muffler	Muffler	Reduction
Exhaust noise level............dbA..	101.5	85.0	16.5
Total sound power...........dbA_p[1]..	120.7	101.9	18.8

[1] Total sound power measurements expressed as dbA_p are referenced to 10^{-12} watts; this is not to be confused with noise levels that are dbA referenced to 20 $\mu N/M^2$.

FIGURE 1. - Mucka muffler manufactured by H. K. Porter Co.

The effect that the muffler has on the sound power frequency distribution of the exhaust noise is shown in figure 2. As can be seen, the muffler is most efficient in the frequency range of 500 to 4,000 Hz.

It should be noted that the drill operating pressure for these tests was 80 psig. Insertion of the muffler produced back pressure ranging from 2 to 4 psig. The drill that was used for these tests was a Gardner-Denver S-58 sinker drill.

Acme Muffler

The second unit to be tested was developed for the Le Roi LSC-75 drill and is distributed by the Acme Machinery Co. of Huntington, W. Va. It basically is a canvas cylinder approximately 10 inches in length with an inside diameter sufficient to permit it to be installed around the drill housing. At both ends, the muffler is clamped to rubber endpieces, which are molded to the contours of the drill housing as shown in figure 3. The internal makeup of the muffler consists of two layers of ordinary felt separated by another layer of canvas material. This system weighs approximately 5 to 6 pounds and costs about $65. The lifetime of the canvas muffler, depending on the handling and the amount of oil and dirt saturation from underground use, is approximately 2 to 3 months. Replacement cost is $25.

Evaluation of this muffler was also conducted outdoors in a semifree field, with the drill in an unloaded (nondrilling) condition. Sound power

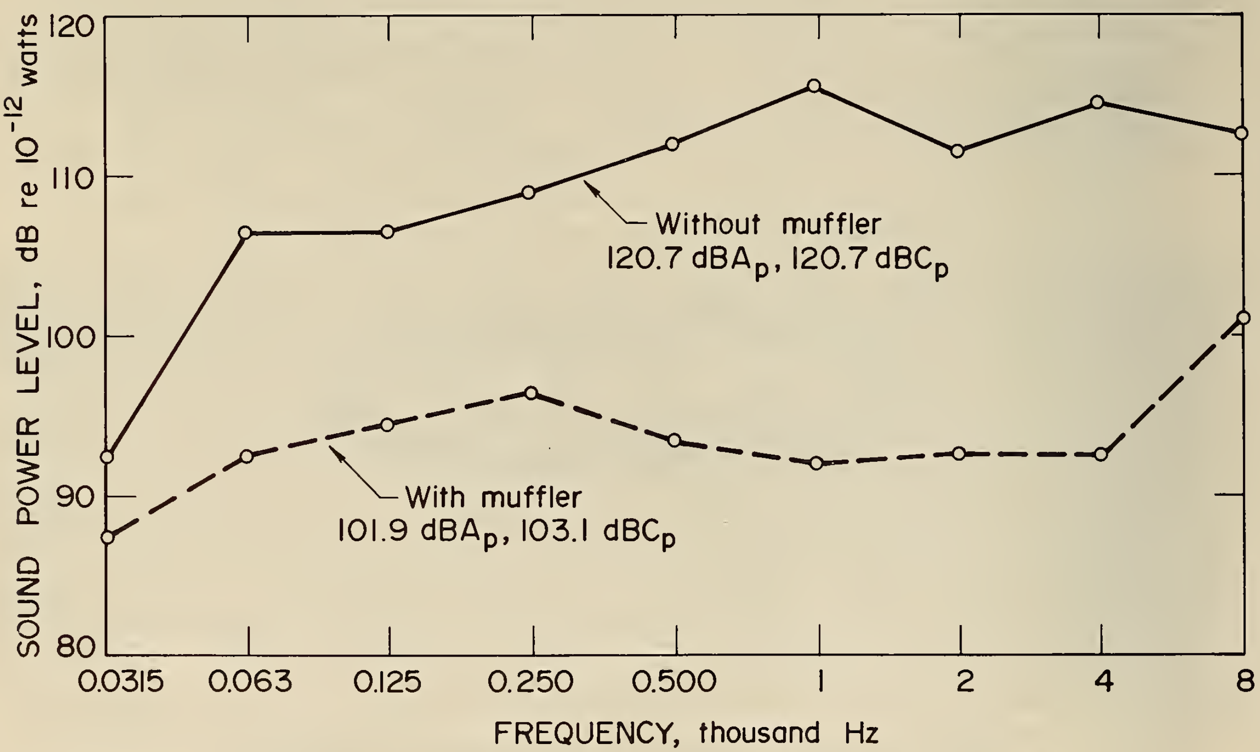


FIGURE 2. - Comparison of the sound power spectra for the Mucka muffler evaluation.

FIGURE 3. - Muffler kit available from Acme Machinery Co.

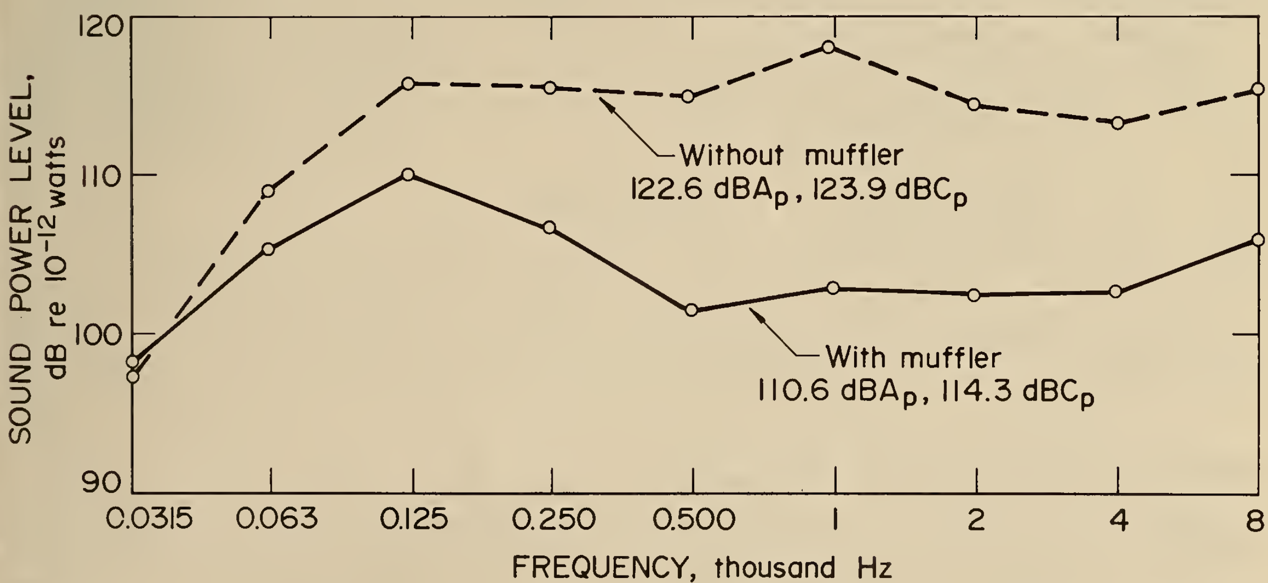


FIGURE 4. - Total sound power spectra of a Le Roi stoper with and without the Acme muffler.

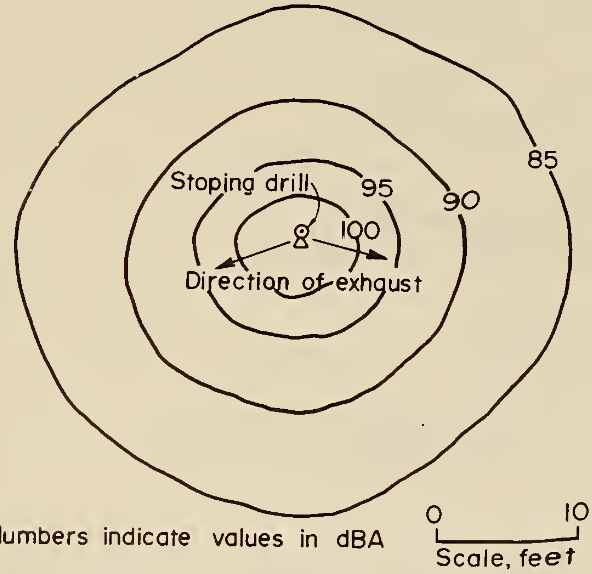
data were obtained for the muffled and unmuffled drill. These results are summarized in the following tabulation:

	No muffler	Muffler	Reduction
Exhaust noise level............dbA..	117.5	103.5	14.0
Total sound power...........dbA_p[1] ..	122.6	110.6	12.0

[1] Total sound power measurements expressed as dbA_p are referenced to 10^{-12} watts; this is not to be confused with noise levels that are dbA referenced to 20 $\mu N/M^2$.

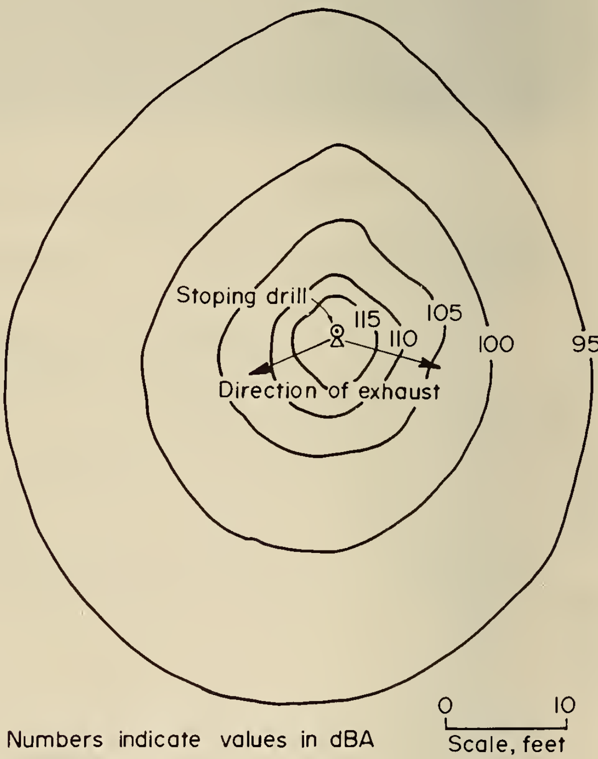
Figure 4 shows the effectiveness of the Acme muffler in reducing the total sound power level of the LSC-75 drill. Again, the muffler is most effective in the frequency range from 500 to 8,000 Hz.

Additionally, measurements were taken with an acoustically calibrated sound level meter at various predetermined locations to determine equal loudness contours around the drill. Figures 5-6 show the contours with the muffler installed and removed, respectively. The noise reducing properties of the muffler are clearly demonstrated in figure 7, which is a comparison of the 95-dbA contours, and in figure 8, which is a comparison of the 100-dbA contours.



Numbers indicate values in dBA

FIGURE 5. - Equal loudness contours around the Le Roi LSC-75 drill with the Acme muffler.



Numbers indicate values in dBA

FIGURE 6. - Equal loudness contours around the Le Roi LSC-75 drill without the Acme muffler.

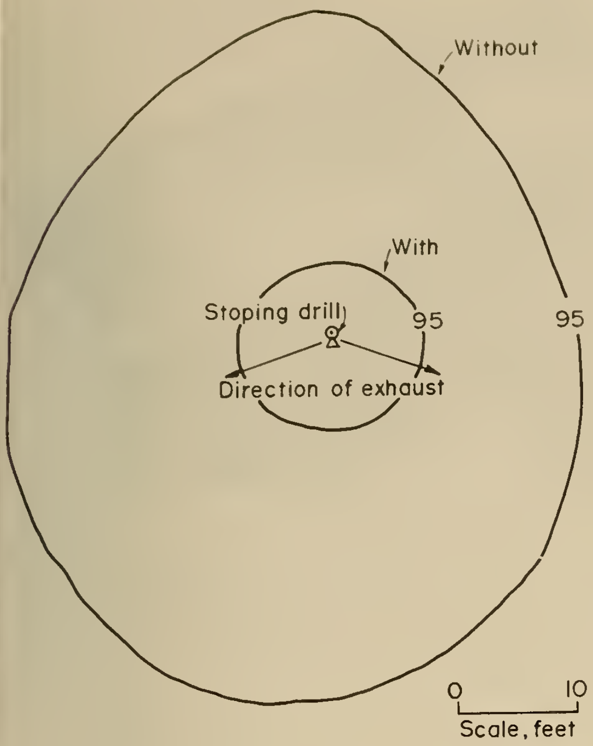


FIGURE 7. - Comparison of the 95 dbA equal loudness contours with and without the Acme muffler.

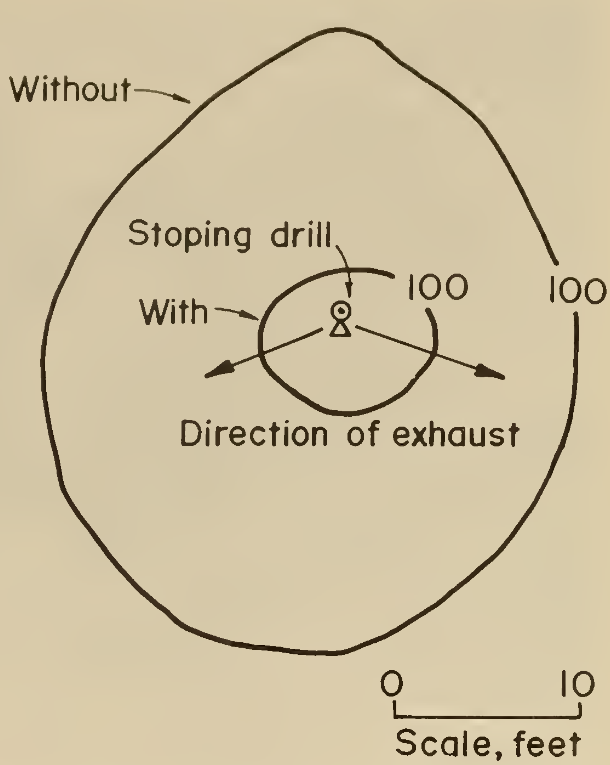


FIGURE 8. - Comparison of the 100 dbA equal loudness contours with and without the Acme muffler.

For the series of tests conducted, the operating pressure of the drill ranged from 75 to 90 psig. Testing has not been conducted by the Noise Group on these mufflers in operation in underground drilling situations; however, results have been reported by a coal company located in central Pennsylvania that the use of this muffler resulted in an overall reduction of 6 dbA, from 120 to 114 dbA.

USSEC Muffler

The third and final exhaust muffler to be evaluated was developed by U.S. Steel Engineers and Consultants, Inc. (USSEC), under contract to the Bureau of Mines. The internal design of these mufflers consists of resonator and expansion-constriction chambers. The external design is a "U" or kidney shape to fit around the jackleg of an Ingersoll-Rand RP38E or a Le Roi LSC-75 stoping drill (fig. 9).

The original mufflers and later models with internal modifications have been tested underground in a number of mines with roof conditions that range from moderately hard shale to extremely hard sandstone. Results from numerous surveys show the range of overall noise reduction to be 6.5 dbA (120 to 113.5 dbA) to 2.5 dbA (116.5 to 114 dbA), depending on the roof conditions and the operating air pressure of the drill. A comparison of the noise spectra

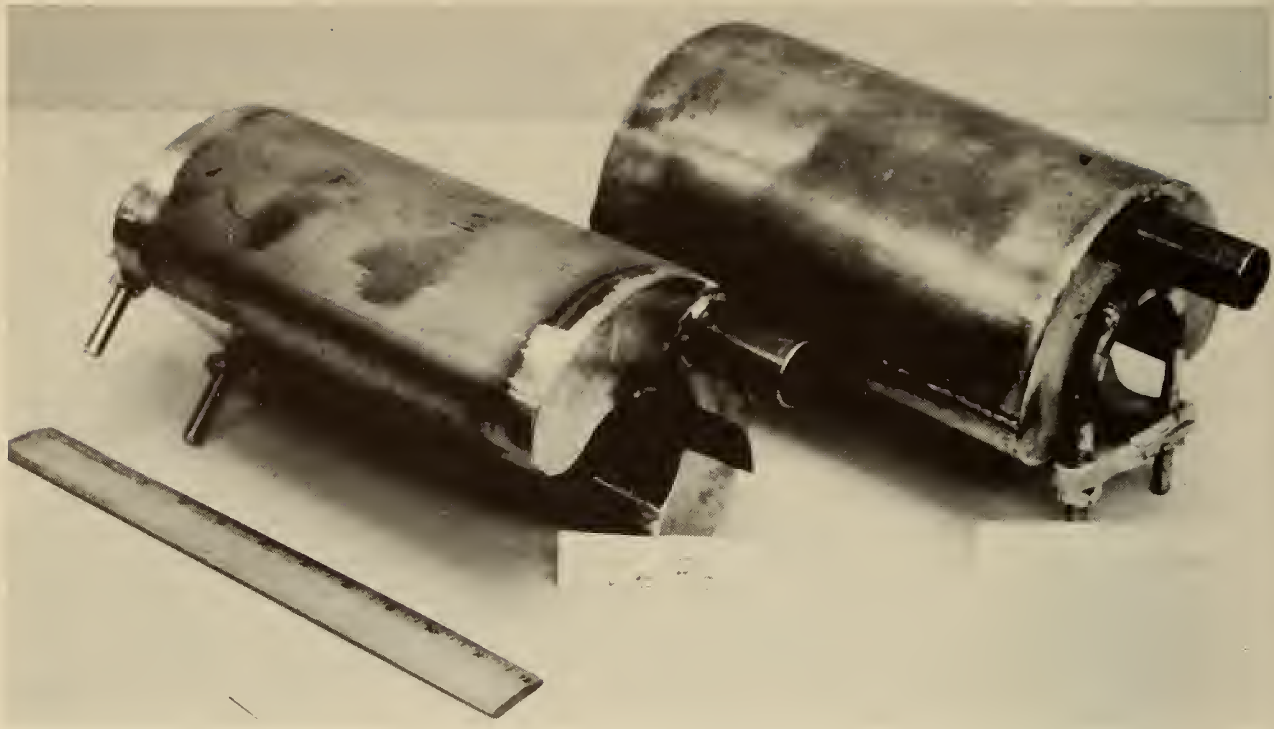


FIGURE 9. - Two kidney mufflers available from U.S. Steel Engineers and Consultants.

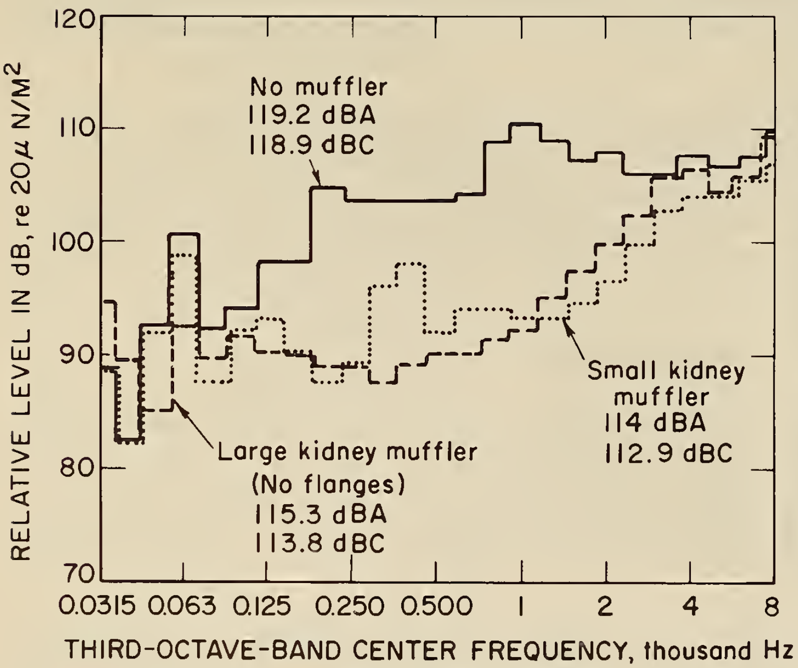


FIGURE 10. - Comparison of the noise spectra of an unmuffled Ingersoll-Rand RP38E drill and two kidney mufflers.

between the unmuffled RP38E drill and two different models of the kidney-shaped muffler is shown in figure 10. The two mufflers tested were (1) an older version, 10 inches in length, which gave an overall noise reduction of 4 dbA, and (2) a new model, 6 inches in length, which gave an overall noise reduction of 5.2 dbA. These values fall in the overall range reported previously. The sound power reduction and the change in equal loudness contours due to the mufflers were not obtained.

Measurements of back pressure caused by the mufflers were approximately 1 to 2 psig. The increase in drill time due to the

mufflers was relatively low, only 10 to 16 percent. The total weight of the muffler and two adapters used to install it on the drill is approximately 10 pounds. The estimated cost of this system is $150.

From all of the previous tests, it can be seen that the use of an exhuast muffler can reduce the overall noise levels 3 to 6 dbA. The resultant overall noise levels would be in the range of 111 to 115 dbA. This sound level range represents the amount of energy that is contributed to the overall level by the mechanical noise of the operating drill. Mechanical noise is dependent on the physical conditions of the drill, the operating air pressure of the drill, and the hardness of the roof being penetrated. The next sections will consider work conducted on the mechanical noise.

INTERNAL MECHANICAL NOISE

A limited amount of work has been conducted in attempting to control the internally produced mechanical noise. To control this noise, three general methods may be used: (1) Vibration damping materials can be applied to various components of the drill in an attempt to eliminate excessive body vibration, thus reducing the amount of airborne noise; (2) the use of high transmission loss materials can be used to encompass the drill housing to reduce the outward radiation of the mechanical noise; and (3) vibrationally damped materials may be used to replace internal parts of the drill that are contributing to the overall noise level.

Thus far, there has been little work conducted pertaining to the first noise control technique, but future work is planned to evaluate the application of damping materials to various parts of the stoping drill.

The second technique can be used in conjunction with an exhaust muffler to make a more effective abatement system. A system of this type, sometimes referred to as a body muffler, has been developed at the Bureau of Mines Research Center in Pittsburgh. The unit, when properly installed, simultaneously reduces both exhaust and mechanical noise emissions.

The body muffler evaluated consists of end caps of flexible urethane material molded to fit the drill housings of the Le Roi LSC-75 and the Ingersoll-Rand RP38E stoping drills (fig. 11). Wrapped around the end caps was a 1/4-inch-thick piece of material designated as E-A-R. This material, which is manufactured by National Research Corp., Billerica, Mass., is a highly efficient energy-absorbing material that possesses internal resistance to motion. The material was then glued together and covered with a sheet of stainless steel to add durability to the system. Included in the bottom end caps were two 1/2-inch-diameter exhaust pipes approximately 12 to 14 inches in length so that the entire system was both an exhaust muffler and a wraparound body muffler. The total weight of this prototype is approximately 12 to 15 pounds.

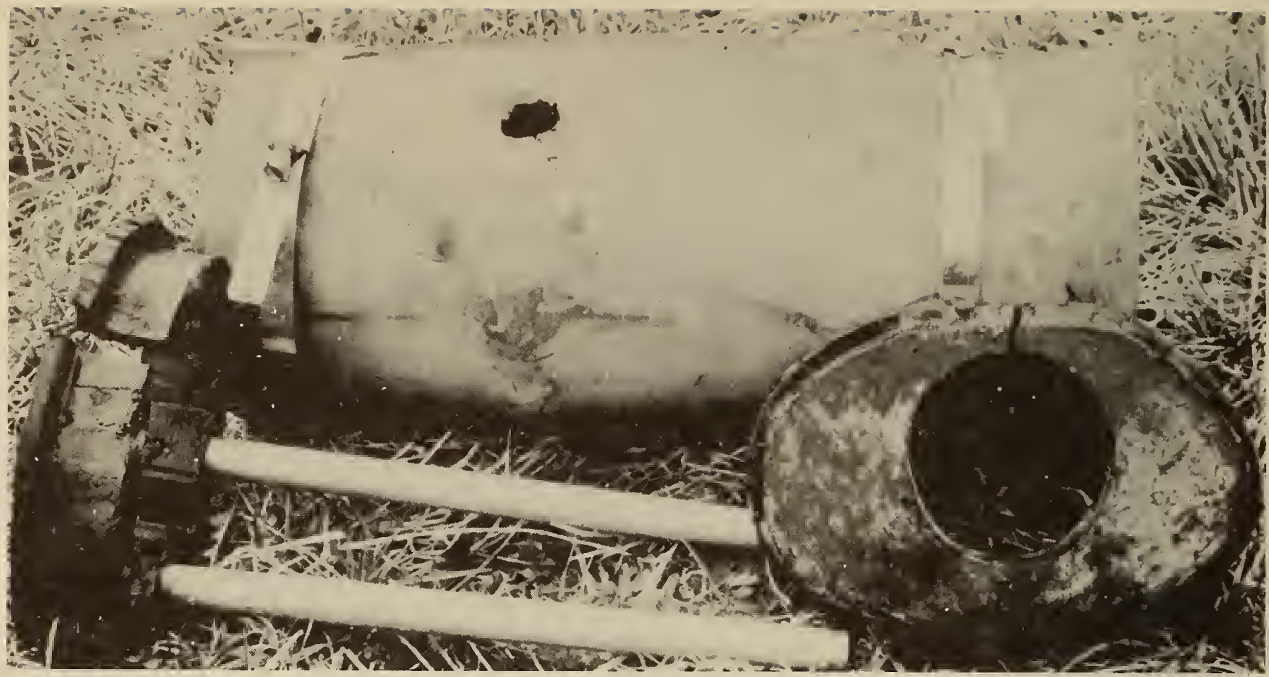


FIGURE 11. - Prototype body muffler developed by the Bureau of Mines Research Center.

Tests were conducted with this body muffler on both drills in a number of underground drilling situations and on the surface in an unloaded condition. The results for the two drills tested are summarized in the following tabulation:

	Le Roi drill	I-R drill
UNDERGOUND, OVERALL NOISE LEVEL		
Unmuffled..................dbA..	120.5±0.9	117.8±1.1
Muffled....................dbA..	110.2±1.0	108.8±1.4
Reduction..................dbA..	10.3	9.0
SURFACE, TOTAL SOUND POWER		
Unmuffled................dbA_p[1]..	122.0	125.9
Muffled..................dbA_p[1]..	108.2	111.0
Reduction................dbA_p[1]..	13.8	14.9

[1] Total sound power measurements expressed as dbA_p are referenced to 10^{-12} watts; this is not to be confused with noise levels that are dbA referenced to 20 $\mu N/M^2$.

The comparison of the frequency distributions for the Le Roi drill, body muffler on and off, tested underground, are shown in figure 12. The reduction of the noise level due to this muffling system, for one typical test, can easily be seen. The body muffler is most effective in the range from 80 to 2,000 Hz. Figure 13 shows the comparison of the sound power spectra for both conditions tested on the surface. Again, the body muffler reduced the sound power levels quite dramatically, with the effectiveness being greatest in the

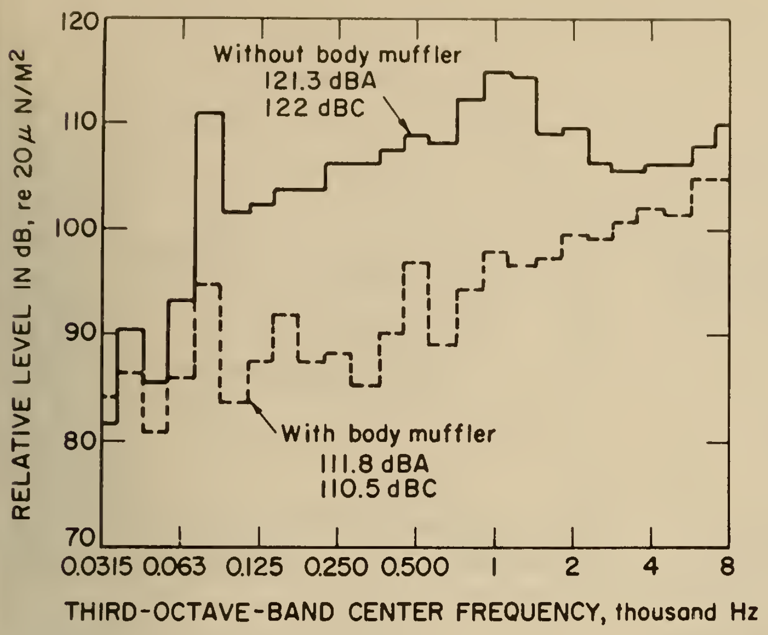


FIGURE 12. - Comparison of the noise spectra for the Le Roi LSC-75 drill, with and without the body muffler.

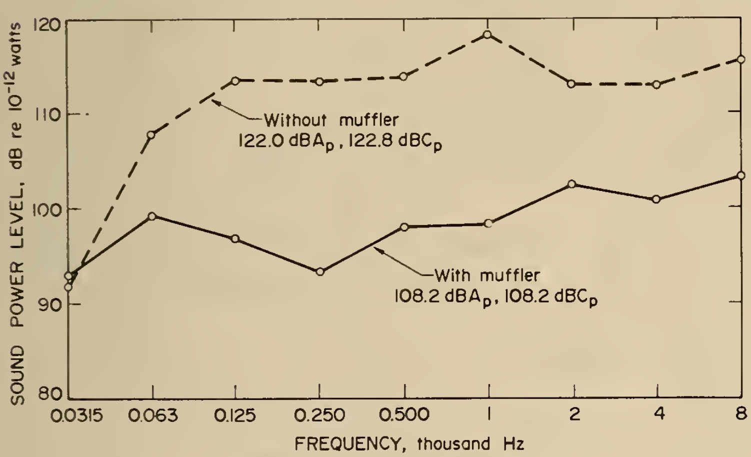
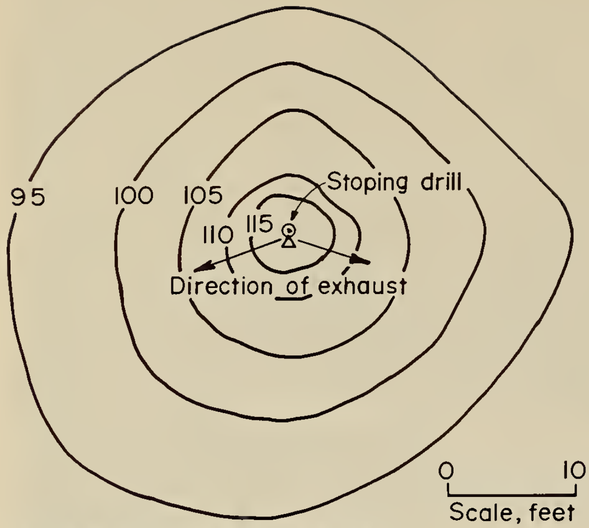


FIGURE 13. - Sound power spectra of a Le Roi LSC-75 drill, with and without body muffler.

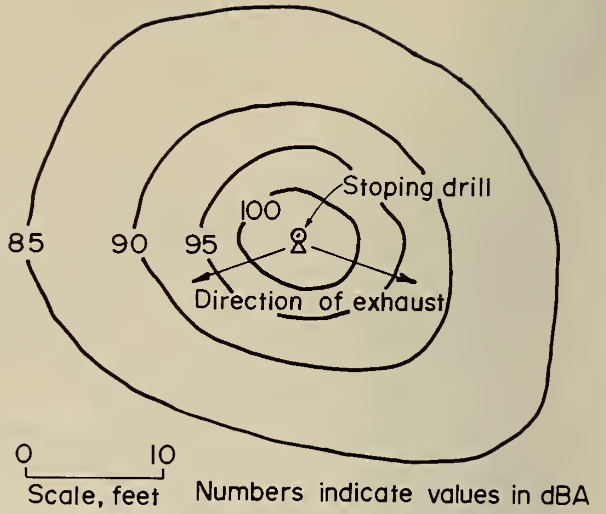
frequency range from 125 to 8,000 Hz. Figure 14 shows the equal loudness contours around the drill with the body muffler off, and figure 15 shows the contours around the drill with the muffling system installed. Comparing these two figures, the reduction achieved can be best understood by realizing that the innermost contour represents the noise level to which the drill operator is exposed. The reduction shown in these two figures is greater than that seen in figure 12, but the reduction is explained by the fact that there is less mechanical noise produced when operating the drill in an unloaded condition. The unloaded condition consists of the drill operating with no drill steel inserted in the chuck. Figures 16-17 compare the 95-dbA and 100-dbA contours for both testing conditions. Back pressure and differences in drilling times due to the body muffler were not measured.

Similar testing was conducted on the Ingersoll-Rand stoping drill; the data are shown in the previous tabulation. Figure 18 shows a comparison of the sound power spectra for both test conditions. The reduction due to the muffling system extends across the entire frequency spectra, showing as great an attenuation in the low bands as in the higher frequencies. Figures 19-20 show the contours around the drill with the muffler off and on, respectively. Notice that the installation of the body muffler not only has quieted the stope noise but also has produced nondirectional sound contours. Figure 21, which is a comparison of the 100-dbA contours, shows quite dramatically the attenuation



Numbers indicate values in dBA

FIGURE 14. - Equal loudness contours around the Le Roi drill without the body muffler.



Numbers indicate values in dBA

FIGURE 15. - Equal loudness contours around the Le Roi drill with the body muffler.

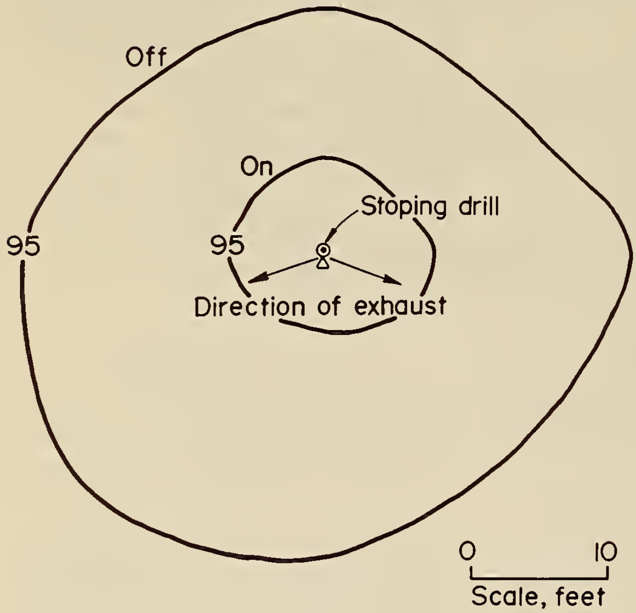


FIGURE 16. - Comparison of the 95-dbA equal loudness contours for the muffler on and off the Le Roi LSC-75 drill.

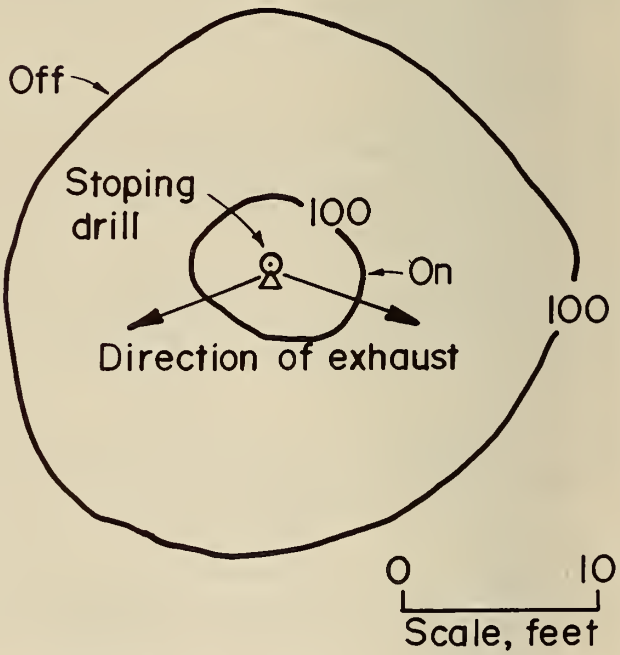


FIGURE 17. - Comparison of the 100-dbA equal loudness contours for the muffler on and off the Le Roi LSC-75 drill.

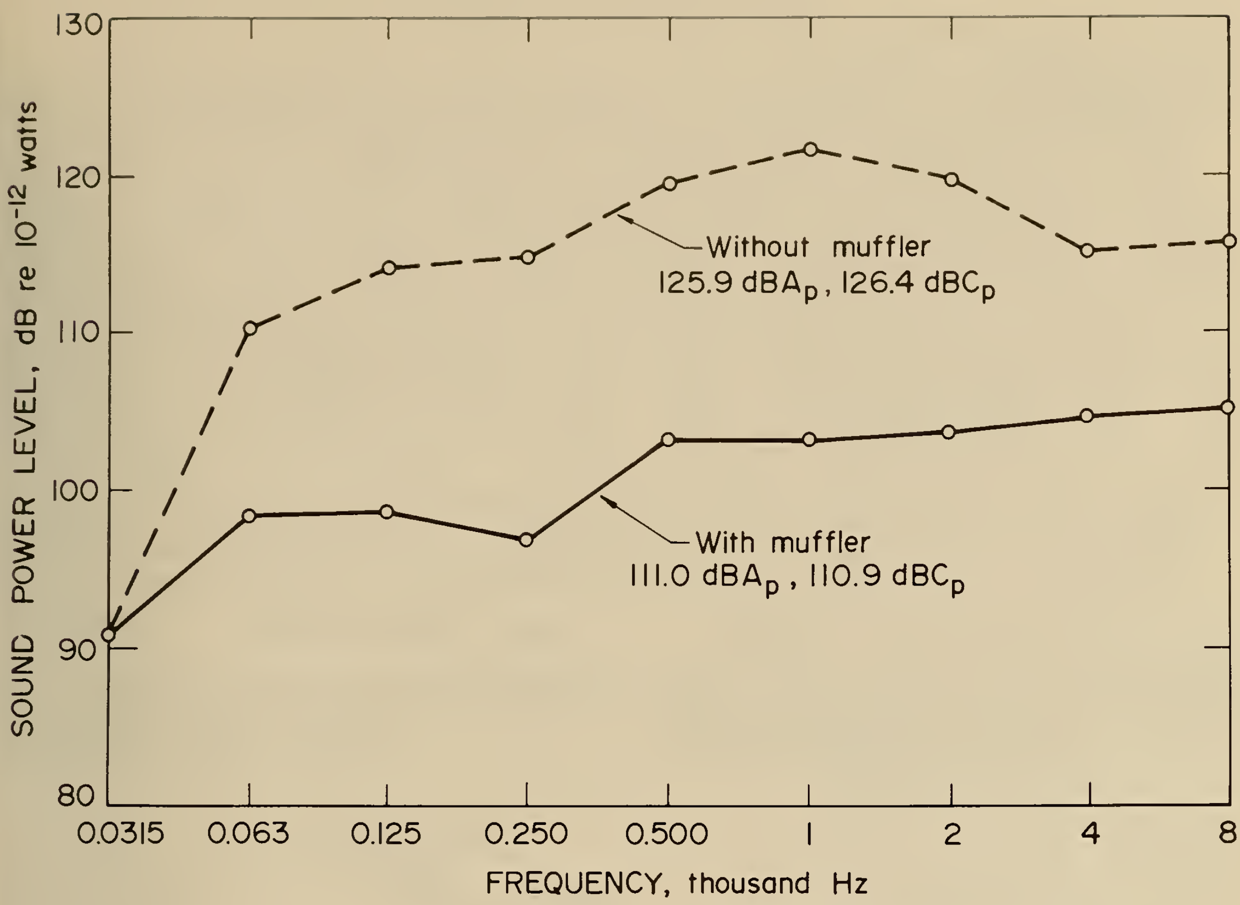


FIGURE 18. - Sound power spectra of an Ingersoll-Rand RP38E drill, with and without body muffler.

characteristics of the body muffler. Figure 22 is a comparison of the two 105-dbA contours.

Additional work, which has been conducted in an attempt to reduce the internal noise at the sources (method c), has been performed at the Rolla Metallurgy Research Center in Rolla, Mo. This involved the use of vibrationally damped alloys for drill piston construction. When the alloy material was subjected to heavy impacting action similar to that of a drill piston, the temperature of the alloy increased rapidly. Conversion of impact energy to heat by the damping alloy accounts for its rapid increase in temperature; since the damping capacity of the alloy decreases with increasing temperature, it tends to temporarily lose its damping properties. The alloy also deformed under impacting, which would make it impractical as a piston material.

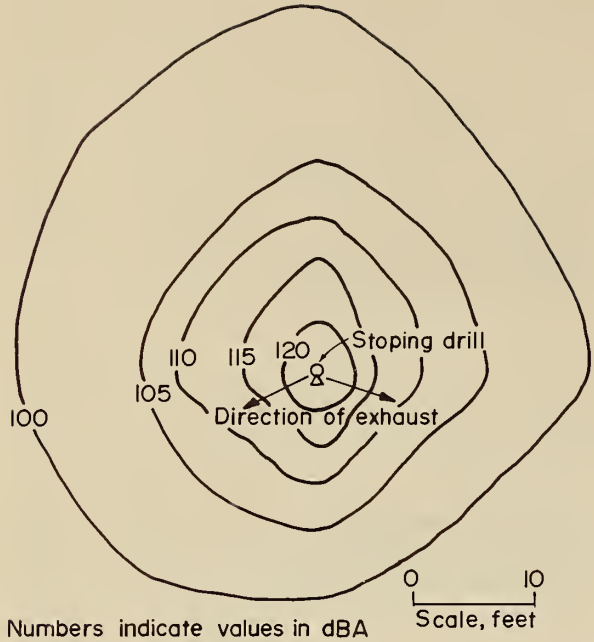


FIGURE 19. - Equal loudness contours around the Ingersoll-Rand RP38E drill, without body muffler.

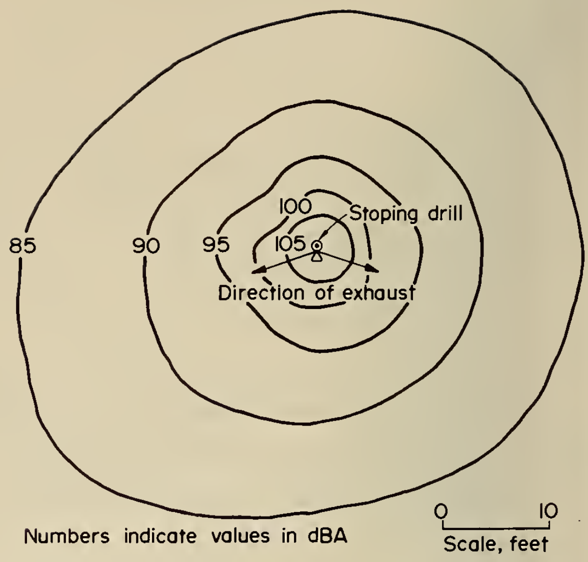


FIGURE 20. - Equal loudness contours around the Ingersoll-Rand RP38E drill, with body muffler.

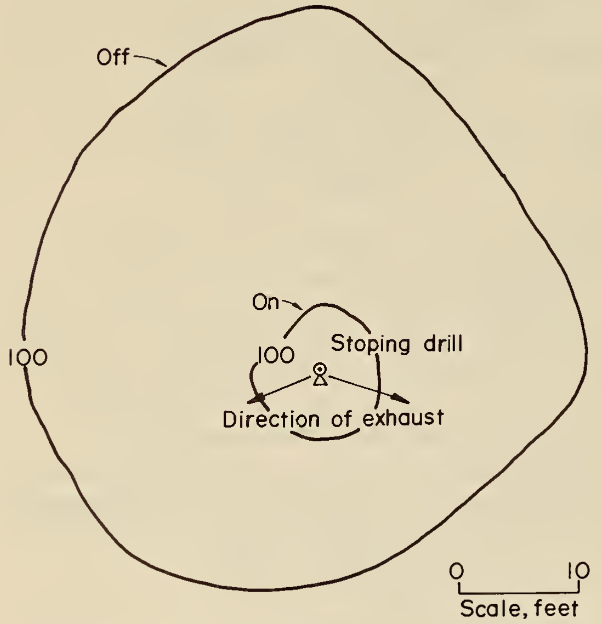


FIGURE 21. - Comparison of the 100-dbA equal loudness contours for muffler on and off the Ingersoll-Rand drill.

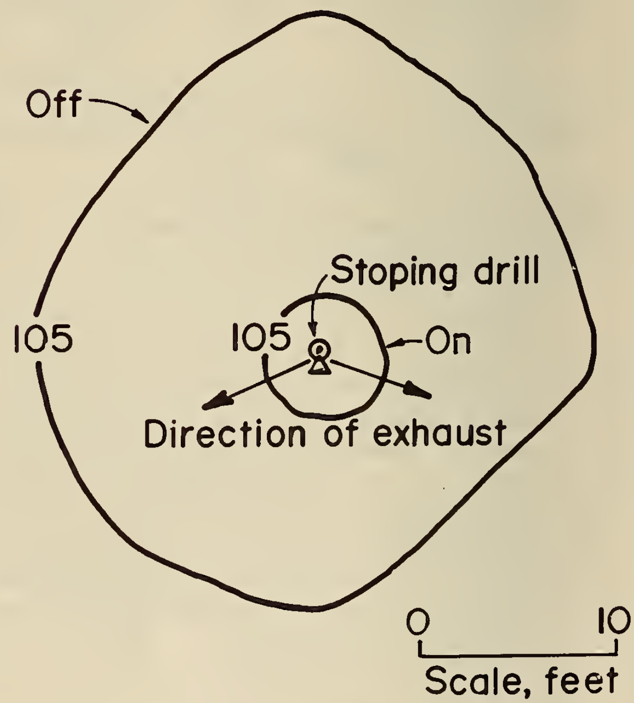


FIGURE 22. - Comparison of the 105-dbA equal loudness contours for muffler on and off the Ingersoll-Rand drill.

EXTERNAL MECHANICAL NOISE

Finally, work that has been done with the third area, the external noise sources, has shown some promising results. Testing by the Pittsburgh Mining and Safety Research Center has shown that the use of partial length constrained layer damped drill steels are effective for controlling the noise from drill steel resonance. The damping consists of a 6- or 7-inch metal sleeve positioned at the end of the drill steel and then filled with a flexible urethane damping material called Flexane. General results from testing these modified drill steels underground have shown an additional 1- to 5-dbA overal reduction, again depending on the roof hardness. Figure 23 shows a comparison of the spectra between a plain and a damped drill steel, both used with an unmuffled Ingersoll-Rand drill. As can be seen, it shows an average reduction of 3 dbA in the overall noise level due to this modification.

The use of the full-length constrained layer damped drill steels would result in more noise attenuation than would the partial length damping, but since the drilling rate is inversely proportional to the drill steel weight, the use of full-length damping would result in a greater loss of drilling efficiency.

Additional work, conducted by the Rolla Metallurgy Research Center, has included the use of alloy materials to replace the present drill rotational chuck. The use of a copper-manganese alloy, in laboratory test conditions, resulted in a 2-db decrease in the noise levels from a new steel chuck and a 3- to 4-db decrease in the noise levels from a worn steel rotational chuck. This indicates that as the drill gets older, the chuck becomes worn and gets noisier because of the loose fit between the chuck and drill steel. It is stated by personnel from Rolla that the decrease obtained from the damping alloy chuck is significant enough to merit serious consideration in industrial drill production.

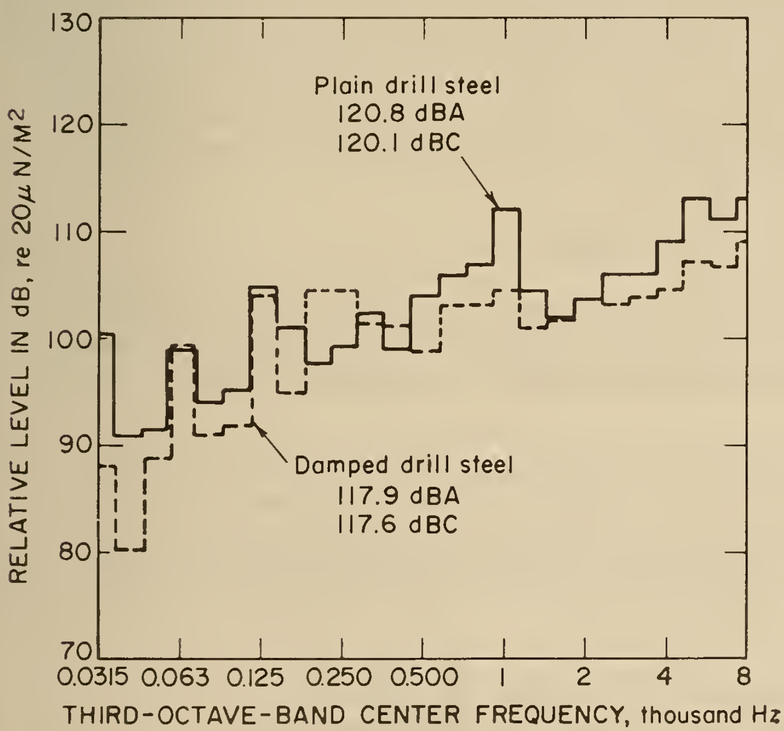


FIGURE 23. - Comparison of the noise spectra between a plain and a damped drill steel on unmuffled Ingersoll-Rand drill.

To reiterate, the general results obtained from the modifications to quiet the mechanical noise have been promising. The use of the body muffler has been

very effective for attenuating the stoper noise. Future modifications to this system may improve the abatement characteristics even further. Alloy materials have been used to replace drill parts with encouraging results. Finally, the use of partial length constrained layers have been effective for damping the drill steel to reduce the amount of noise from drill steel resonance.

A combination of all of the modifications mentioned should be used to effectively quiet the overall noise level of the pneumatic stoping drill. To attempt noise reduction for any piece of equipment solely through retrofitting is both difficult and costly. An easier solution would be to use a quieter drill to replace the noisier stoper.

STOPING DRILL REPLACEMENT

An alternative to the pneumatic stopers would be the use of rotary drills. There have been situations when stopers were used to drill the overlying strata that could have been drilled with the hydraulic rotaries. The cost of the hydraulic rotary drill, which is approximately 10 times that of a stoper, may be the probable limiting factor for these mines.

When the overlying rock is extremely hard, a rotary drill cannot be used. Excessive bit costs prohibit the use of a rotary in such strata. There are attempts by rotary drill manufacturers to modify their products sufficiently to permit their use in hard strata. A percussive action is being incorporated with the rotary motion of these drills to mimic the drilling action of a stoper. Also, a rotary drill has been modified to use wet drilling. By using water to cool the bit, the extremely high costs can be reduced by extending the effective lifetime of the drill bits. The disadvantages of excessive water on a section and the high initial cost of a rotary drill may prevent many mines from purchasing a rotary drill.

CONCLUSIONS

The initial attempts at control of the drill exhaust noise by mufflers have proven to be effective. Preliminary testing of modifications to some of the mechanical noise sources have been promising. Additional work in these areas is definitely needed.

The necessary abatement of the stoping drill noise to bring the drill operator into compliance will not be achieved easily, effectively, or economically by simply modifying the existing equipment. The pneumatic stoping drills will continue to be a major noise problem in underground coal mines until the drill manufacturers begin to redesign them with noise control as a major objective.

Finally, it would be impractical to attempt to completely eliminate the use of stopers in underground mines. There are situations when a rotary drill cannot be used to drill the strata. After any roof fall, the newly exposed material must be bolted before cleanup can commence. It would be impossible to use a rotary drill in such a situation. Because the stopers are portable, easier to maintain, and cheaper to purchase and operate, a thorough redesign effort should be put forth to quiet the pneumatic stoping drill.

APPENDIX.--SOUND POWER MEASUREMENT[1]

The total sound power is the total amount of acoustical energy radiated from a sound source. It can be measured directly in spherical or hemispherical space. Of the two, hemispherical space is more practical since it can be approximated by an outdoors condition with an open area above a hard surface that is free of reflecting objects. The measurement of sound power generated from a source in hemispherical space is based on the premise that the reverberant field is negligible at the positions of measurement and that the total radiated sound power is obtained by a space integration of the sound intensity over a hypothetical test hemisphere centered on the noise source. The surface of the imaginary hemisphere should be in the far field of the source. To assure this, the hemisphere radius should be equal to at least two major source dimensions or four times the average source height above the reflecting plane, whichever is larger. Also, the test hemisphere is positioned so its center is located on the reflecting plane beneath the acoustic center of the source.

After an appropriate radius for the test hemisphere is chosen, the space average of the mean square sound pressure over the hemisphere is determined. This is done by dividing the hemisphere into several segments of equal area S_i. The sound pressure level at the center of each of these segments is measured experimentally. The number of measuring segments needed is dependent on the required accuracy and the directivity of the source. The sound pressure level at each microphone location is converted into a mean square sound pressure ratio using the following equation:

$$L_{p_i} = 10 \log \left(\frac{P_i}{P_{ref}} \right)^2 ,$$

where L_p = sound pressure level at ith microphone location,

P_i = sound pressure at ith microphone location,

P_{ref} = reference sound pressure 20 $\mu N/M^2$,

and $\left(\frac{P_i}{P_{ref}} \right)^2$ = mean square sound pressure ratio.

The space average mean square sound pressure ratio $\left(\frac{\overline{P}_h}{P_{ref}} \right)^2$ is obtained using the following equation:

$$\left(\frac{\overline{P}_h}{P_{ref}} \right)^2 = \frac{1}{2\pi r^2} \sum_{i=1}^{N} S_i \left(\frac{P_h}{P_{ref}} \right)^2 ,$$

[1] For a more detailed discussion on sound power measurements, refer to Noise and Vibration Control, edited by L. L. Beranek, McGraw-Hill Book Co., Inc., New York, 1971.

where S_i = area of ith segment,

r = radius of hemisphere,

and N = total number of microphone locations.

The space average sound pressure level is then

$$L_{p_h} = 10 \log \left(\frac{\overline{P}_h}{P_{ref}} \right)^2 .$$

The total sound power level L_w is then calculated using

$$L_w = L_{p_h} + 20 \log r - 10 \log 2\pi.$$

If desired, the total sound power w can be obtained using the following equation:

$$L_w = 10 \log \frac{w}{w_{ref}} ,$$

where w_{ref} = reference sound power 10^{-12} watts.

NOISE CONTROL OF STRIP MINE VEHICLES

by

Leonard C. Marraccini[1]

ABSTRACT

This paper describes some examples of practical noise control for strip mine vehicles. Although the discussion centers around dozers and front-end loaders, the noise control technique can be applied to other heavy equipment such as trucks or scrapers. The techniques used in this paper involve exhaust mufflers and acoustically treated cabs to reduce the noise levels.

INTRODUCTION

Noise problems exist in strip mine operations just as in other aspects of mining. In strip mine operations, the noise can affect the vehicle operator, men working nearby, and also nearby residences. The noise levels at the operator's position can vary with different equipment and work cycles. For example, front-end loaders and dozers can have a noise level from 95 to 105 dbA. Heavy-duty trucks can range from 95 to 100 dbA. In this paper, some practical examples of noise control on dozers and loaders will be discussed.

NOISE CONTROL TECHNIQUE AND APPLICATION

In any noise control work, there are three main areas that can be affected. These areas are the source, the path, and the receiver. Basically, the source is the various components in the machine that produce the noise. This can be the pumps, motors, exhausts, or the tracks. The path is the route the noise travels from the source to the receiver. This route can be through the air or through the machine frame. The receiver is the operator of the machine or persons nearby who hear the noise. With respect to noise control, two areas were the objects of investigation. These were the source and the path. In regard to the source, exhaust mufflers were evaluated. In regard to the path, acoustically treated cabs were evaluated.

One example of attempting noise control techniques at the source involved an HD-41 dozer. In this particular case, an evaluation was made on the noise-reducing properties of exhaust mufflers only. An initial noise survey was performed on the untreated dozer to determine the noise levels at the operator's position and at several locations away from the dozer. The noise level at the operator's position was 104 dbA. Next, two exhaust mufflers were installed by maintenance personnel (fig. 1). This work was done onsite.

[1] Supervisory physicist, Mining Enforcement and Safety Administration, Pittsburgh, Pa.

FIGURE 1. - Installation of mufflers.

After the installation of the mufflers, a second noise survey was conducted under conditions identical to the first. This second survey was used to determine the effectiveness of the exhaust mufflers on noise reduction. Results showed that the overall noise level at the operator's position remained unchanged at 104 dbA; however, noise levels measured at various distances away from the dozer showed significant noise reduction.

To better illustrate the effects of the exhaust mufflers on noise levels at various distances from the dozer, the following figures were made to illustrate contour lines of equal noise levels. Figure 2 shows the contour lines of equal noise levels around the dozer without exhaust mufflers.

In figure 3, the contour lines of equal noise levels are shown around the dozer with exhaust mufflers. As can be seen, the directivity pattern of the noise has changed as well as the noise levels.

Thus, based on the tests performed on the HD-41 dozer, it was found that exhaust mufflers did not reduce the noise levels at the operator's ear. This occurred because noise from various other machine components was transmitted

FIGURE 2. - Contour lines of equal sound—no muffler.

FIGURE 3. - Contour lines of equal sound—with muffler.

through the floor and sides of the cab to the operator. However, as shown in figures 2-3, the noise levels in areas around the dozer were significantly reduced.

The exhaust mufflers used in the investigation cost approximately $800 per pair. It took approximately 12 man-hours for installation, and the dbA noise reduction at a distance of 50 feet from the dozer was 8.3 dbA. With respect to the cost of the mufflers and the dbA reduction obtained, one could say that cost per dbA reduction was $96.39. This is relatively inexpensive compared with the cost of the dozer itself. There are various manufacturers who commercially sell exhaust mufflers. A condensed list of some manufacturers are in table 1.

The second example of practical noise control with regard to the path involved a D-988 front-end loader. In this particular case, an evaluation was made on the noise reduction properties of an acoustically treated cab. An initial noise survey was performed on the loader with an untreated cab to determine the noise levels at the operator's position. The loader was then taken into a nearby shop and the cab was removed. Specialized personnel began to install the acoustic material. This material is shown in figure 4.

TABLE 1. - Manufacturers of exhaust mufflers

Manufacturer	Address
Donaldson Co., Inc........................	P.O. Box 1299 Minneapolis, Minn. 55440
Eckel Industries, Inc.....................	155 Fawcell St. Cambridge, Mass. 02138
Industrial Acoustics Co...................	1160 Commerce Avenue Bronx, N.Y. 10462
Riley-Beaird, Inc., Maxim Silencer Div....	P.O. Box 1115 Shreveport, La. 71130
Universal Silencer Div., Nelson Industries, Inc.	P.O. Box 9 Libertyville, Ill. 60048

This acoustic material was composed of a high-density plastic sandwiched between two layers of urethane foam. The surface of this material was treated with a vinyl covering as protection against the dirt, grease, etc.

Basically, there are two methods that could be used to install this material. One method involves the application of an epoxy binder between the cab wall and the acoustic material. The second method, the one used in this particular study, involved a novel type spot-welding system patented by Tube-Lok Corp. In this type of installation, the metal surface of the cab was first cleaned of dirt, grease, rust, etc. Next, metal studs were spot-welded to the surface of the cab with a special spot-welding gun. The operation of this gun is shown in figure 5. Next, the acoustic material was pressed onto the metal studs (fig. 6). Finally, plastic buttons were screwed onto the end of the studs to secure the acoustic material to the surfaces of the cab (fig. 7).

The finished cab was then placed back on the loader. A followup noise survey was conducted under conditions identical to the first to determine the effectiveness of the acoustically treated cab. Results showed that with the cab doors closed, the noise levels at the operator's position were reduced from 99 dbA to 89 dbA. In regard to compliance with the Federal law, the loader operator could now run the loader for 8 hours instead of approximately 2 hours.

In this particular case, the acoustic material in kit form, installed by specialized personnel, cost approximately $2,000. It took approximately 24 man-hours for installation, and as shown, resulted in a 10-dbA noise reduction at the operator's position. In respect to the cost for the acoustic material and the dbA reduction, one could say that the cost per dbA reduction came to $200 per dbA; however, further reduction beyond 10 dbA would cost more in the sense that individual noise components would have to be separately treated. A condensed list of various manufacturers who sell acoustic materials for heavy

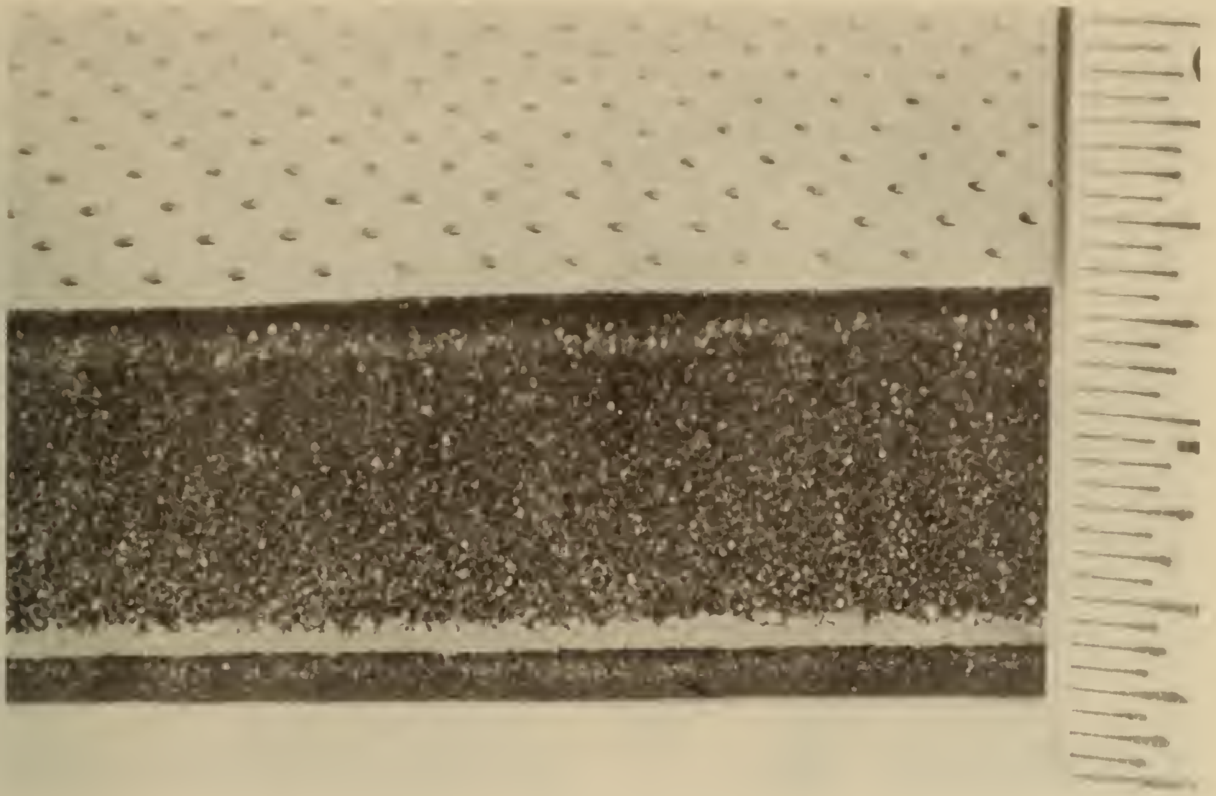


FIGURE 4. - Acoustic material.

FIGURE 5. - Spot-welding gun.

FIGURE 6. - Acoustic material pressed into studs.

FIGURE 7. - Installing plastic buttons onto studs.

equipment is shown in table 2. Some companies offer do-it-yourself kits or kits installed by trained personnel.

TABLE 2. - Manufacturers of acoustically treated cabs

Manufacturer	Address
Industrial Acoustics Co..........	1160 Commerce Avenue Bronx, N.Y. 10462
Korfund Dynamics Corp............	30 Cantiague Road Westbury, N.Y. 11590
Soundcoat Co., Inc...............	175 Pearl Street Brooklyn, N.Y. 11201
J. M. Tull Industries............	285 Marietta Street, NW Atlanta, Ga. 30302
Tube-Lok Corp....................	4644 SE 17th Avenue Portland, Oreg. 97202

Next, two additional examples will further illustrate noise control using exhaust mufflers and acoustically treated cabs; two points will be emphasized. The first is the effect of combining mufflers and acoustic cabs. The second is that the dbA reduction due to acoustic cabs is critically dependent on the method and thoroughness of application of the material.

One example dealt with the combined effect of exhaust mufflers and acoustic cabs on a D-9 dozer. In this particular case, with no acoustically treated cab and no exhaust muffler, the noise level at the operator's position was 104 dbA. With a do-it-yourself method of application of acoustical material on the cab and still no exhaust muffler, the noise level was reduced to approximately 99 dbA. Finally, with the acoustically treated cab and exhaust mufflers, the noise level at the operator's position remained at 99 dbA. Thus, in this case, the acoustically treated cab did reduce the noise level somewhat, but the exhaust muffler did not.

The second example dealt only with acoustically treated cabs. The work was again done on a D-9 dozer. The noise level at the operator's position in an untreated cab was 104 dbA. The cab was then treated with acoustical material by specialized personnel. With the acoustically treated cab, the noise level at the operator's position was reduced from 104 to 93 dbA.

CONCLUSIONS

Through several examples, you have seen the practical techniques of noise control for strip mine equipment. Exhaust mufflers on the vehicles is one solution to community-type noise problems or noise exposure of people working near strip mine vehicles. Acoustically treated cabs are one solution to noise affecting the vehicle operator. Although practical treatments have been discussed only in reference to dozers and loaders, the same technique can be applied to trucks and other heavy equipment.

NOISE CONTROL IN COAL CLEANING PLANTS

by

W. N. Patterson,[1] E. E. Ungar,[1]
and G. Fax[1]

ABSTRACT

To minimize the risk of permanent hearing loss for workers in the coal industry, Congress has decreed through the Coal Mine Health and Safety Act of 1969 that no worker is to be exposed to noise levels greater than 90 dbA continuously during an 8-hour shift period without the implementation of a hearing conservation program. To comply with the provisions of this act, coal cleaning plant operators have three options. For one, they may adjust the work schedule or location for each worker such that the worker exposure to existing noise is reduced. The second option is to quiet or cover the sources of noise to which workers are exposed. Finally, ear protectors may be provided to workers. In terms of true compliance with the spirit of this act, the second option is the most desirable. This paper focuses on the means and costs required to quiet a coal cleaning plant. The sources of noise along with the typical worker exposure is given as an indication of what plant machinery needs to be quieted, the degree of quieting required, and how to achieve that quiet. From this, the plant operator may more accurately judge the procedures required to quiet his plant and the expected costs.

INTRODUCTION

The process machinery required to accurately remove the rock from coal also often produces an unwanted byproduct, noise. Worker exposure to this noise varies, but typical in-plant noise levels are greater than 90 dbA for all unshielded areas. Figure 1 shows some worker locations and the range of noise levels measured. To provide an environment that minimized the risk of permanent hearing damage, plant noise levels, where workers are present, should be less than 90 dbA. The varied noise sources associated with coal cleaning machinery need to be examined in detail to determine the "best" noise reduction technique to be employed for each source.

Separation of rock or refuse from coal is a beneficial scheme that has evolved from hand picking to extensive mechanical separation processes over the years. Present coal cleaning plants encompass many different mechanical processes, all of which use specific gravity differences to accomplish separation. In spite of the diversity of the process machinery, certain common noise sources are found in all plants.

[1] All of Bolt Beranek and Newman, Inc., Cambridge, Mass.

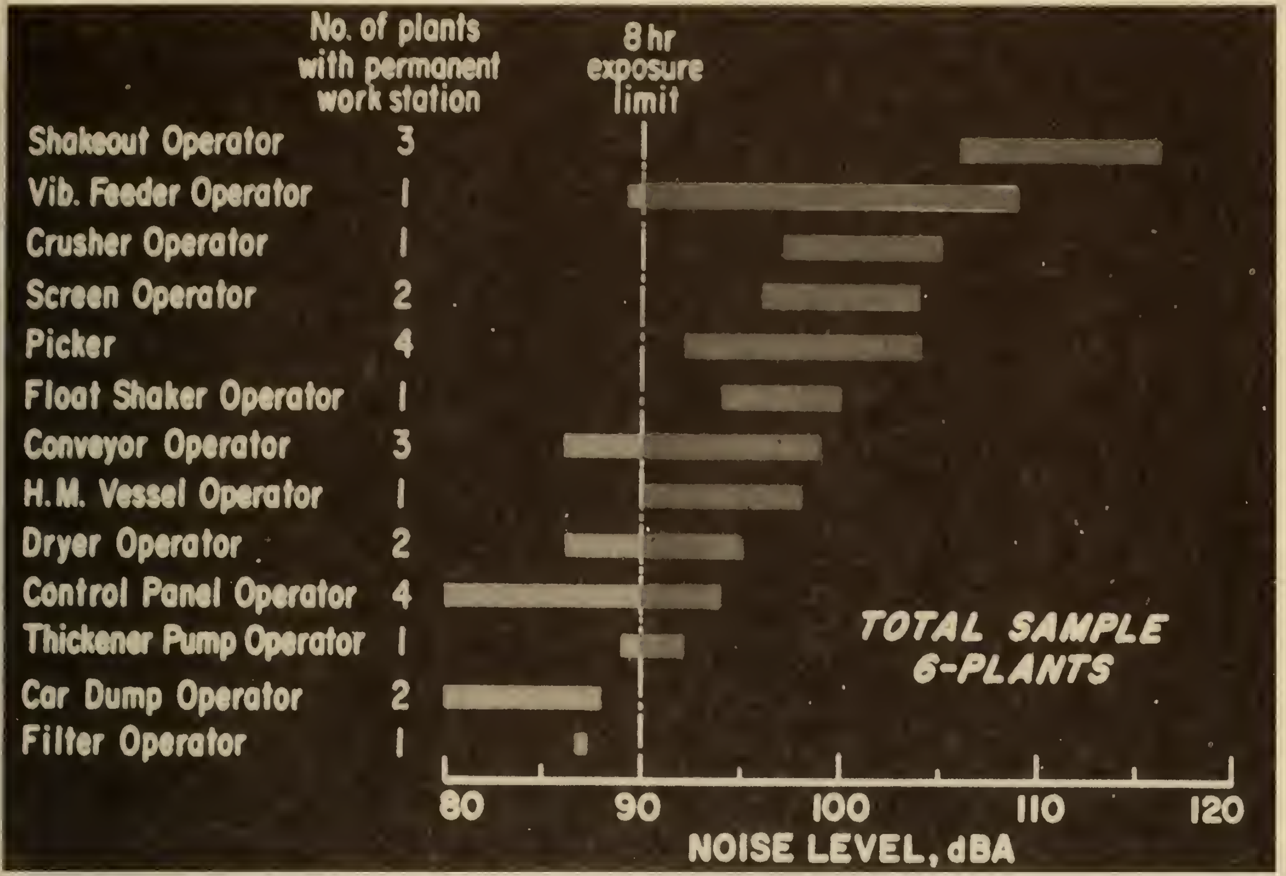


FIGURE 1. - Ranges of noise levels at various permanent work stations.

NOISE SOURCES AND REDUCTION

Screens

The most common noise source is screen related. Coal screens are classified by type (inclined, horizontal, reciprocating, shaking) and function (scalping, sizing, desliming, drain, and rinse). For noise control purposes, the primary distinction is between slow action, inclined, screens--typically used for scalping and sizing--and fast action, small opening, horizontal screens, as shown in figure 2. The primary source of noise in slow action screens is the coal-deck impact. Noise control for these screens consists of a resilient decking to reduce the impact. For fast action screens, two sources of noise are present, the coal-deck impact and the shaking drive mechanism. Noise control of fast action screens is more difficult since the decking hole size is smaller, precluding a thick resilient deck, and the shaking mechanism excites the screen frame with subsequent noise radiation. Consequently, both sources need to be treated for reduction of screen noise.

Replacement of the steel deck with a rubber-coated or other resilient deck would reduce the severity of impacts and the associated noise. Reductions on the order of 5 to 10 dbA may be expected for the impact-related

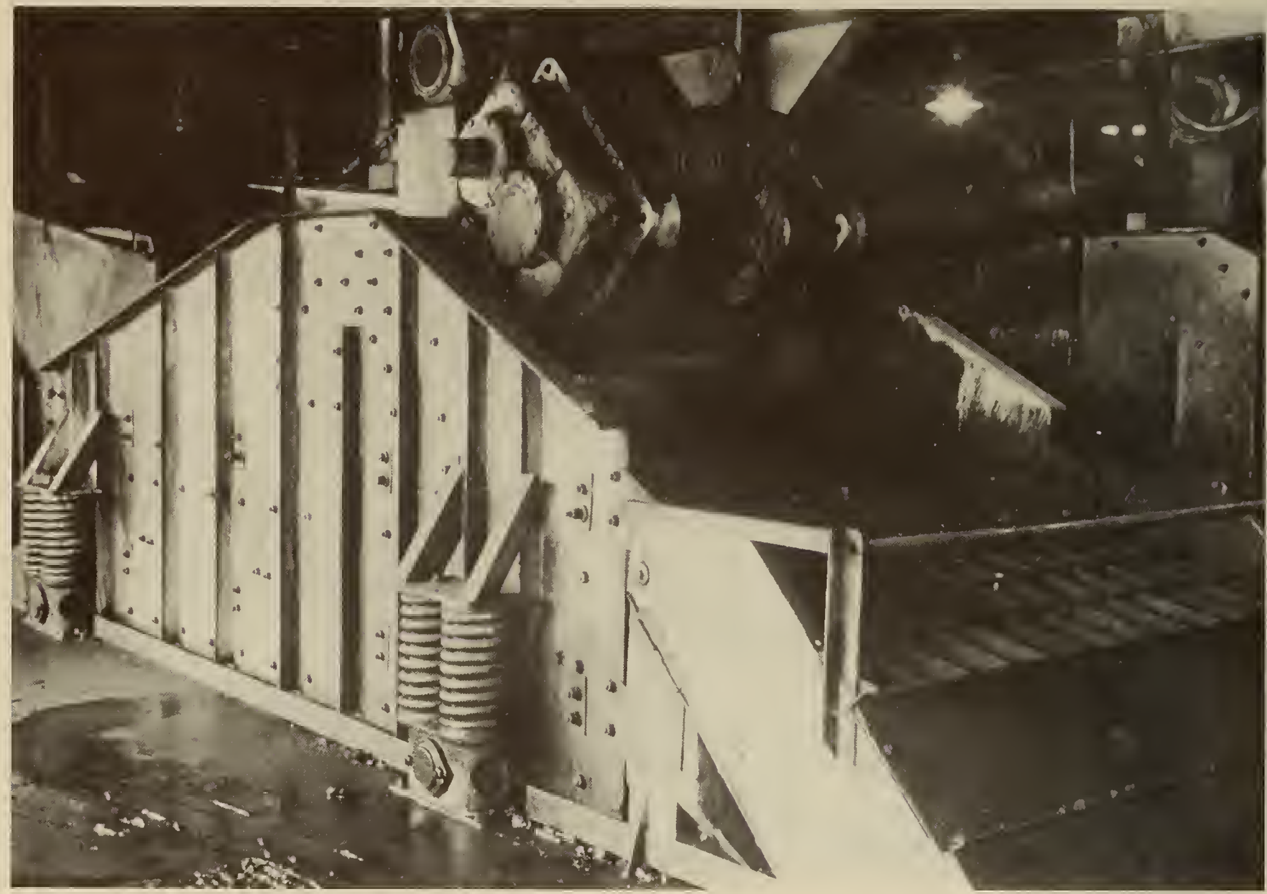


FIGURE 2. - Fast acting horizontal screen.

component of screen noise, but the total noise reduction would be only between 2 and 8 dbA; the 2 dbA corresponds to screens processing clean bituminous (soft) coal, and the 8 dbA corresponds to screens handling refuse or anthracite (hard) coal.

The performance and economic advantages and problems of rubber-coated and similar decking are not clear. Although the initial cost of rubber-coated decking is about three times that of conventional decking, the estimated life of rubber-coated decking is about three to five times that of steel decks. Some operators state that rubber decking would not work for processing fine coal, that larger deck area is required to process the same flow rate, and that the rubber-coated decking would require additional structural support. On the other hand, some plant experience has shown these drawbacks to be either minimal or absent, and in at least one instance, an increased flow rate has been achieved with the same surface area. The initial cost of rubber-covered decking is estimated to be $1,000 to $2,000 additional per screen over that of conventional decking.

Reductions of impact severity and the associated noise may be obtained also be reducing the stroke and speed of the shaking mechanism. Noise reductions of 5 to 10 dbA are estimated to be achievable. The related direct costs

would be minimal (corresponding only pulley and throw changes), but the process flow rate might be reduced, so that this approach is not likely to be acceptable economically.

It is recommended that rubber-coated decking be given first consideration and that an enclosure be used if rubber decking will not reduce the screen area noise level to below 90 dbA. If the noise produced by the empty screens is below 87 dbA, rubber-coated screens may be expected to reduce the (full) operating noise level to below 90 dbA. If the noise level produced in the screen area by the empty screens is above 87 dbA, control of mechanical vibrations is required, as discussed later.

Reduction of the noise contributed by the eccentric weight driving mechanism may be achieved by use of gearing manufactured to closer tolerances and tighter bearings. Corresponding reductions of 5 dbA are possible, at a cost differential of about $100 for new screens or $300 for retrofit of old screens. Alternatively, one may consider covering the mechanism with a closely fitting enclosure that is acoustically lined and vibration-isolated from the case. Noise reductions of up to 10 dbA are possible, at an estimated cost of about $200 per unit; however, the associated cooling and maintenance problems are not known.

When noise is caused by a chattering of screen supporting spring against the mount pad or screen frame, one may insert a resilient pad between the spring end and screen structure to obtain perhaps 5 dbA of noise reduction at a cost of about $50 per screen. Alternatively, one may replace the steel springs with air bags. The cost is higher, on the order of $300 per screen, but field reports indicate that air bag supports produce a reduction of the total screen-related noise, which may be as high as 15 dbA, depending on the stiffness of floor supports.

Where the foregoing noise reduction treatments are not feasible, one needs to consider enclosures. Enclosures for dust-control purposes are currently available for production-model screens. It would not be difficult to add acoustical absorption to the interiors of these enclosures, thus increasing their acoustic effectiveness. When purchased with the screen, a dust-control enclosure typically costs $7,000 to $10,000; interior acoustic treatment would perhaps add another $300 to $600. There is some concern among operators that enclosures would prevent visual inspection of screen decks, thus hindering removal of refuse and clearing plugged holes; however, the dust-control enclosures presently in use in the coal cleaning industry seem to be quite acceptable.

Chutes

Another common source of coal cleaning plant noise is the chutes used to direct the coal and refuse during gravity fall. The noise generating mechanism in chutes is the coal-plate impact. Reduction of chute-related noise requires a reduction of the impact force or the response of the plate to the impact. This reduction may be accomplished through the use of resilient liners to reduce the impulsive force or the use of massive plates or liners to reduce the deflections of the plate.

Impact noise reductions of about 5 dbA can be achieved by lining the chute with a rubber or similar covering. The availability, wear, repairability, and costs of suitable coverings are described as favorable by the material manufacturers when compared with those of typical steel plates.

A widely employed approach consists of placing welded ledges or similar obstructions to the flow of material into the chute, so that a layer of material remains in the chute. This layer then shields the chute surface from the impacts. The expected noise reduction is about 5 dbA. Utility of this approach is limited to cases where the flow obstructions created by the chute inserts can be tolerated. One line that has been installed primarily for wear but affords some noise reduction is used rails as shown in figure 3.

The addition of mass to chutes, in the form of concrete liners on the inside (as are often used for wear reduction) or of metal plating or sandbags on the outside, may also be expected to contribute several dbA of noise reduction at limited cost.

The same statements apply also to the use of structural damping materials adhered to the exterior surfaces, except that their safety and costs for coal preparation plant applications are not known.

FIGURE 3. - Rail sections used as chute liner for wear and noise reduction.

Hoppers and Bins

The noise problem associated with hoppers and bins must be attacked by reducing the vibrations of their panels. This may be accomplished by mass-loading the panels with material--most simply keeping the hopper or bin full or nearly full. Alternatively, additional mass (steel panels, sand, etc.) can be added to the outside. One may also consider rubber linings on the insides, especially in the area where direct impact occurs. Noise reductions of 5 to 10 dbA should be achievable with any one of these approaches. The first, of course, implies an operational constraint, but no other cost. The other approaches imply potential structural (weight) problems, as well as unexplored maintenance complexities and costs estimated at $500 (for material) per hopper or bin.

Casing Noise of Blowers, Pumps, Dryers, and Motors

Mechanical drive units, blower casings, and crushers exhibit similar noise generation characteristics. Source levels of 95 dbA at 5 feet are typical; the noise emanates from the casing from vibrations generated by gear meshing and other mechanical forcing.

The simplest means for reducing the noise radiated owing to vibrations of surfaces of machinery consists of the addition of a close-fitting enclosure that is vibration-isolated from the machinery casing. Reductions of casing noise by 10 dbA are typical. The costs may be expected to vary according to the size and complexity of the casing to be enclosed; estimates range from $200 to $1,000 per unit. Enclosures must be designed to permit adequate cooling and any required access for maintenance, inspection, and lubrication. The cooling problem can be alleviated somewhat by adding ducts at the bottom and top to induce a chimney draft of cooling air.

Enclosures like those discussed in the previous paragraph also apply for gear drive casings. Noise control at the source would involve use of closer tolerance gears and bearings; use of such gears and bearings should provide noise reductions in excess of 5 dbA with no changes in efficiency or maintenance requirements. The added cost is about 10 percent of the cost of conventional gears, or typically about $300.

Noise radiation from double roll crushers may be reduced by keeping the material inflow uniform. Since most of the perceived noise from crushers is radiated by the external casing and gearing, noise control may be achieved by reduction of the gearing tolerances and backlash and by use of tighter bearings. If such modifications cannot be implemented or if the resulting noise reduction is insufficient, then an enclosure should be placed around the crusher and associated gearing. This enclosure would need to be provided with acoustically treated ducts at the inflow and outflow positions. The cost of improved gearing is difficult to estimate until the required tolerances are known; a complete crusher enclosure is estimated to cost $2,000 for labor and materials.

Car Shakeouts

The pounding of the shakeout mechanism against the railroad car side cannot be reduced without reducing its efficiency for unloading the car. Padding of the contacting surfaces or clamping the shaker to the car sides would reduce the noise but would also reduce the efficiency of the unloading operation. The only practical means for dealing with the noise of shakeouts consists of providing an enclosure for the shakeout operator and his helper. This enclosure must provide at least 40 db of noise reduction. Thus its walls and ceilings need to be built of massive panels, its door should be self-closing with airtight rubber seals, and its windows must be double glazed. The cost for each such room is likely to be between \$10,000 and \$20,000.

Replacement of an installation requiring car shakeouts with a rotary dump carloader is rarely feasible and also costly (\$1,000,000 per rotary dump) but would eliminate the shakeout noise problem.

Picking Tables

In some plants, it is feasible to eliminate the inherently noisy jobs of pickers by replacing picking tables with a rotary breaker. However, such breakers are economical only for high throughput rates. Breakers are expensive, costing from \$35,000 for a small unit (9 feet in diameter by 12 feet in length) to \$100,000 for a large one (13 feet 6 inches in diameter by 32 feet in length). They are heavy, weighing 45,000 to 143,000 pounds, and require considerable supporting structure. The cost of installation, including construction of supports and changing conveyor lines, is approximately the same as the purchase price of the unit.

Because of their size, rotary breakers are usually located outside the plant building. Therefore, they may create a community noise problem. This can be overcome by purchasing dust-control hoods and treating them with interior acoustic absorptive material, which would add about \$7,000 to \$10,000 to the cost of the unit.

It is estimated that a rotary breaker can be installed while the picking tables are still on line, with the changeover in operation taking place after the breaker is installed. Little plant downtime would therefore be required.

If rebuilding of the plant as discussed previously is not feasible, one may construct a partial barrier between the picker and the table. This would have to be built to suit the local circumstances and would have to be designed not to interfere with the picking action. Estimated cost for such a barrier, installed, is \$1,000 to \$2,000.

Blowers and Fans

The in-plant noise associated with blowers and fans that transport air into enclosed spaces comes primarily from the air inlets. This noise typically has dominant pure-tone (single frequency) components at frequencies that correspond to the rotor lobe or fan blade passage rates and their harmonics.

Noise control can best be accomplished by means of mufflers or ducts affixed to the inlet port. Where the predominant noise is a single tone at a fixed frequency, mufflers tuned to this frequency can be quite useful. If the dominant noise consists of a multitude of pure tones and/or broadband noise, then a muffler consisting of a long, labyrinthine, acoustically lined duct is required for muffling purposes.

Alternatively, one may duct the inlet to the outside of the coal plant, thus removing the noise source from inside the plant. Either mufflers or ducts should provide about 10 db of noise reduction if they are well designed acoustically; greater amounts of noise reduction are available if large mufflers and heavy wall ducts are acceptable. Estimated costs for simple mufflers or ducts vary between $200 and $1,000 per unit, depending on the complexity of the system.

Pumps

Vacuum pumps are similar to blowers; they take air from an enclosed space and exhaust into the plant. Here the exhaust, rather than the intake, is the dominant noise source. The same muffler and ducting noise control approaches for the intake port of a blower apply to the exhaust port of a vacuum pump, at similar cost. The noise radiated from the shell of snubber tanks that are used in conjunction with vacuum pumps may best be reduced by providing this tank with a sheet metal wrap that is isolated from the shell by a resilient material. Such a wrap might cost approximately $100 per unit and should provide about 10 dbA of noise reduction.

Liquid pumps are not significant noise sources, but if noise treatment should be needed, it can best be obtained by means of an isolated wrap around the casing, as discussed previously for snubber tanks. Reductions of 10 dbA should be attainable at costs of a few hundred dollars per unit.

Valves

Water valves are not a significant noise source. Air valves have been found to produce significant noise levels; valves similar to baum jig air valves tend to be extremely noisy owing to the explosive and hissing noise associated with the venting process. The noise control methods applicable to air valves are the same as those for blower and fan inlets: the valve exhaust must either be muffled or ducted to the outside of the plant. The estimated associated cost is from $200 to $1,000 per valve.

Air Blasts

Air blasts that are used to aid the material flow in chutes and hoppers generate a loud hissing noise due to the high air exit velocity and impingement of the airstream on solid surfaces. Reduction of the noise of air blasts should be achievable by a redesign of the exit nozzle or fitting to provide a lower exit velocity. Reducing the exit velocity by only 20 percent should result in little loss of material moving performance but can reduce the noise by several decibels. The associated cost should be minimal, perhaps $100 to $200 per unit.

Waterfalls

Although the noise levels produced by waterfalls rarely are as significant as others, simple perforated deflection shields, introduced above the impingement locations to slow and split the flow, may be used to provide noise reduction of 5 to 10 dbA at relatively little cost.

Conveyors

No simple means is available for quieting the noisy squeal of flighted drag conveyors. Lubrication of the rubbing surfaces (with water or oil) might work but has not been tried. Where possible, drag conveyors should be replaced with rubber-belted conveyors for noise control purposes. Costs of such replacement are high, unless this replacement is made as part of a plant modification program undertaken for other reasons.

Other Equipment

Noise control of electromechanical vibrating feeders may be accomplished by replacing them with mechanical feeders; this would lead to a net noise reduction of 10 dbA. Enclosing electromagnetic feeders or isolating them from workers by acoustic barriers may provide up to 15 dbA of noise reduction, at a cost of about $2,000 per unit.

Rap sieve bins that are used to classify coal are constantly tapped by hammers, resulting in impact noise, noise due to mechanical vibrations, and air exhaust valve noise. Since the rapping is required for proper machine function, one can only enclose the tapping hammers and provide mufflers for the air exhaust, or one may provide an enclosure for the entire machine. Costs would be about $2,000 for up to 10 dbA noise reduction.

ACOUSTICAL ABSORPTION IN PLANT SPACES

All of the noise control approaches discussed previously have centered on quieting of machines or enclosing of the workers. The use of sound-absorbing materials, placed on the walls and ceilings, should also be considered.

However, the addition of such materials is useful only if the sound field in the plant areas is reverberant; that is, consists largely of reflections from the walls, ceiling, and floor. Measurements (table 1) have shown that this is not the case in most plants; thus, little would be gained by use of acoustically absorbent materials in these plant areas.

To provide a plant-wide worker environment that has a sound level below 90 dbA, all of the machines or systems ranked 1 through 5 in table 2 must be quieted. If a combination of engineering noise control and worker placement and/or scheduling is to be used, only those machines or systems ranked 1 through 4 need quieting. If acoustic barriers are placed between all the noise sources ranked 4 and the associated worker locations, then quieting only the machines ranked 1 through 3 should provide acceptable worker noise

exposures. The third proposal represents the minimum noise control required to meet the letter of the required worker exposure limitations.

TABLE 1. - Average acoustical absorption coefficients measured in coal preparation plants

Octave band center frequency, Hz	Absorption coefficient in--	
	Large rooms	Small rooms
63	0.3	0.15
125	.3	.15
250	.4	.15
500	.4	.11
1,000	.5	.12
2,000	.5	.15
4,000	.5	.17
8,000	.8	.15

TABLE 2. - Rank-ordering of equipment in terms of noise

Rank	Equipment	Typical sound level at worker position, dbA	Typical worker proximity
1	Car shakeout.................	110-120	2 workers, full time.
2	Screens......................	95-105	Predominant in-plant noise source; many workers, often near full time.
3	Picking tables...............	90-105	1 worker, full time.
4	Blowers, dryers, air pumps, fans, crushers, air valves, feeders, flighted conveyors, chutes.	90-105	Maintenance and operational support workers.
5	Motors, gear drives, liquid pumps, hoppers.	85-95	Do.
6	Belted conveyors, diester tables, flotation cells, waterfalls, rotary pumps, heavy media vessels, cyclones.	75-85	Do.

Quieting an entire plant to 90 dbA or less will entail an initial capital cost and possibly some additional operating expenses. Table 3 lists the equipment found in a medium-sized plant of 700 tons of raw coal per hour feed. Note that many of the noise control techniques (rubber liners, ledges, trough treatment) may provide reduced operating expenses.

We have seen that coal cleaning plants comprise a collection of noise sources inherent with the coal cleaning process. Reducing the in-plant noise levels to be less than 90 dbA will require extensive rework. Some of the noise reduction techniques require coal flow and impact modifications that

provide side benefits of longer wear life and less maintenance. For these reasons, the quieting of coal cleaning plants are not as expensive as initial capital costs indicate in the long run and provide the benefits of an improved worker environment where communication is possible, detection of abnormal operation is enchanced, and the danger of permanent hearing damage is reduced for all workers.

TABLE 3. - Cost of quieting a medium-sized plant (700 tons per hour)

Equipment	Number of units	Typical noise level, dbA	Noise control method	Unit cost	Total
Baum jigs............	1 Type J	100	Mufflers (10)..........	$500	$5,000
Do.................	1 Type M	95	Damp sides.............	2,000	4,000
Rotary dump..........	1	85	None...................	-	-
Scalping screens (reciprocating).	1	98	Rubber lining..........	2,000	2,000
Picking table (reciprocating).	1	98	Damping and partial enclosure.	2,500	2,500
Crushers.............	2	100	Enclosures.............	2,000	4,000
Refuse screens (shaker drive).	2	100	Rubber lining enclose drive.	2,700	5,400
Clean coal screens (shaker drive).	8	95	Rubber lining enclose drives.	2,700	21,600
Centrifugal dryers....	6	95	Enclosures.............	1,000	6,000
Disk filters.........	2	85	None...................	-	-
Vacuum pumps.........	2	95	Mufflers, lagging......	1,500	3,000
Roots blowers........	2	95	Mufflers, enclosures....	2,500	5,000
Conveyors (flighted)..	3	90	Damp trough, blades.....	5,000	15,000
Conveyors (belt)......	3	80	None...................	-	-
Conveyor drive........	6	95	Enclosures.............	1,000	6,000
Chutes...............	21	90	Ledges, lining, damp....	300	6,300
Diester tables........	12	85	None...................	-	-
Vibrating feeder......	1	90	Partial enclosure......	2,000	2,000
Fans.................	1	95	Muffler................	700	700
					88,500

DISCRIMINATING EARMUFF

by

John Durkin[1]

ABSTRACT

As borne out by various studies, exposure to sound level in excess of 90 dbA for a sufficient time will cause hearing loss. Consequently, the Coal Mine Health and Safety Act of 1969 limited the noise exposure of underground miners.

Although earmuffs and plugs provide hearing protection, they also interfere with normal communications and the ability to hear warning signals during quiet periods. The Bureau of Mines has developed an earmuff that has no attenuation at sound pressures below 83 db but limits the maximum received level to about 90 dbA. This provides the wearer with protection without sacrificing safety.

INTRODUCTION

Over the past few years in the coal mining industry, there has been an increased awareness of the physical impairments that can result when an individual is continually exposed to high sound pressure levels. Figure 1 shows a pure tone audiogram of four groups of individuals. The hearing level is measured for specific frequencies called pure tones and marked on the chart. It can be seen that the hearing level for both groups of coal miners is below that of the nonnoise exposed group. A significant point can be seen from the figure: The nonnoise exposed group between the ages of 50 and 59 can generally hear better than coal miners in the 20-to-29-year-old age group.

Another important problem that occurs when an individual is exposed to high noise levels is illustrated in figure 2. This graph shows the reduction in hearing level following a 2-hour exposure to noise equivalent to that of a roof bolter. The zero line represents the hearing level before exposure. Note that hearing gradually recovers over a period of time but that recovery is still not complete even after 24 hours. This effect is called "temporary threshold shift."

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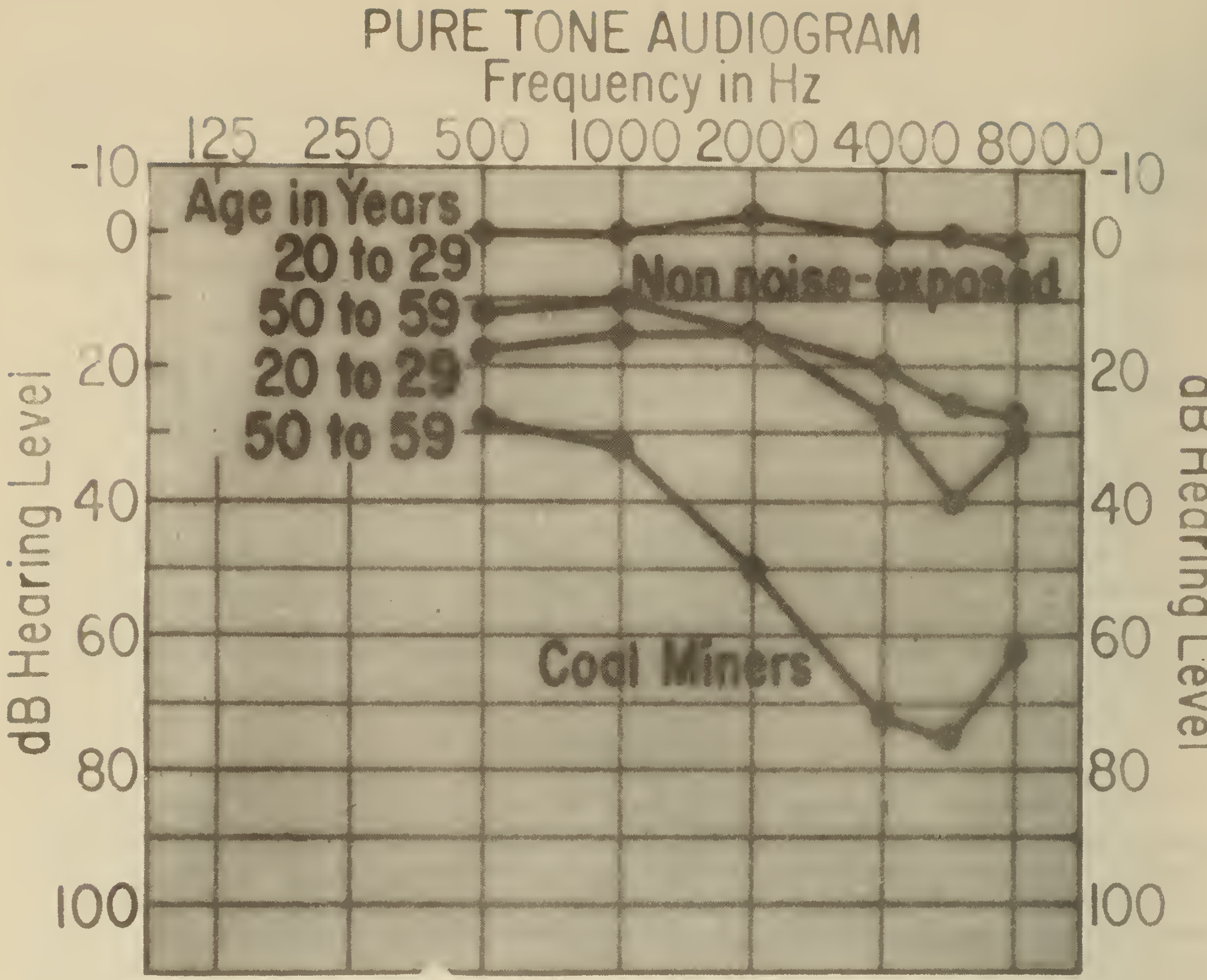

FIGURE 1. - Pure tone audiogram showing hearing sensitivity of non-noise-exposed workers and coal miners on two different age groups.

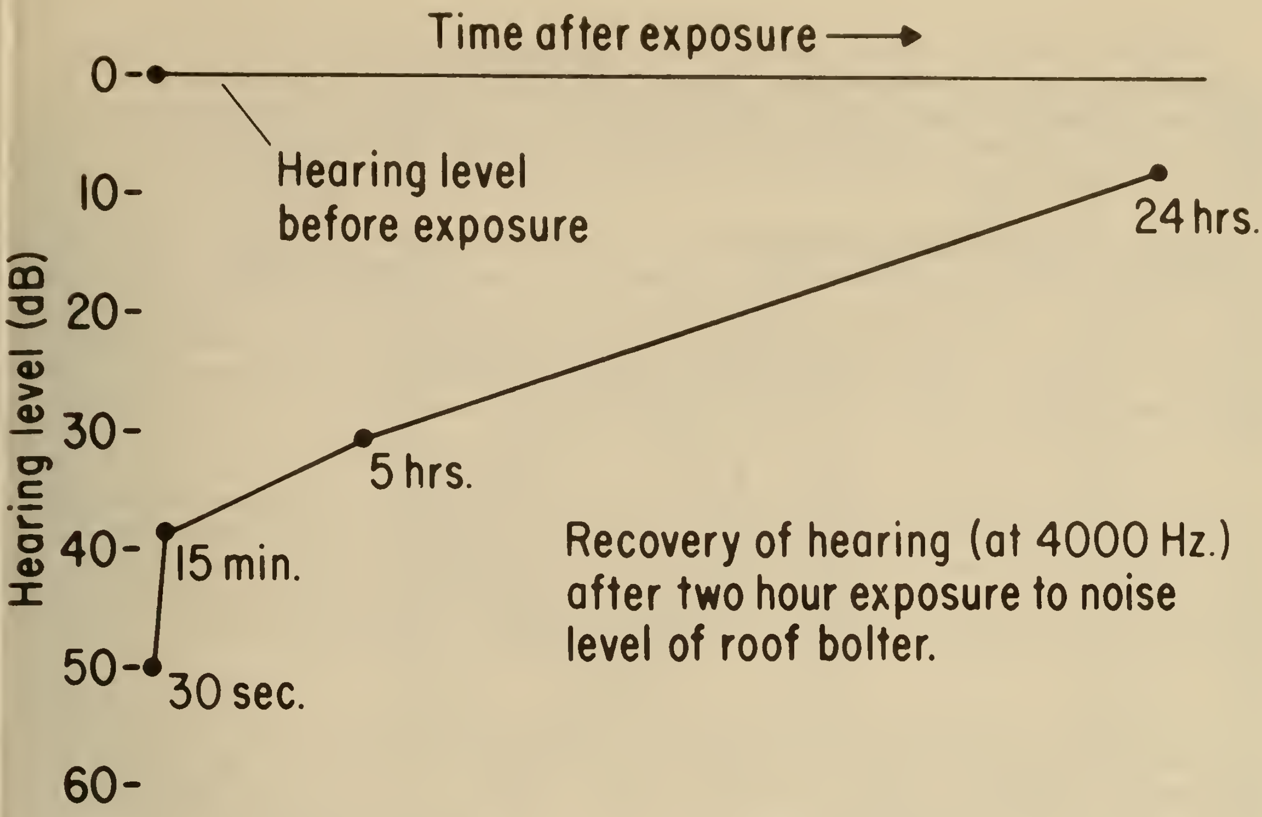

FIGURE 2. - Hearing recovery after high noise exposure.

The Coal Mine Health and Safety Act of 1969, Public Law 91-173, specifies that mandatory noise exposure standards be developed. Such standards have been established and are shown in table 1. This study based on 40 years of occupational exposure shows that an individual can be exposed up to 8 hours a day at 90 dbA, 6 hours at 92 dbA, and so on, before hearing damage will result. Although the ultimate solution is engineering control or abatement of noise sources (an extensive Bureau of Mines program is directed toward that end), the present answer in many cases is the use of ear protection. Earmuffs are preferred to ear plugs because of hygiene problems underground.

TABLE 1. - Permissible noise exposures

Duration per day, hours	Sound level, dbA
8	90
6	92
4	95
3	97
2	100
1-1/2	102
1	105
3/4	107
1/2	110
1/4	115

However, section 206 of Public Law 91-173 also specifies that in complying with the mandatory standards, controls may not include protective devices that may otherwise impair the safety of the miner. Hence the question of whether ear protection jeopardizes a miner's ability to hear sufficiently becomes a major issue.

What is defined here as hazardous is how restrictive any device would be in enabling a miner to hear warning signals and carry on conversation with his fellow worker. The standard earmuff has the adverse effect of attenuating at all sound pressure levels, thereby giving rise to difficulty in communicating at normal levels. Also there is concern that the earmuff interferes with the hearing of warning signals in the form of roof talk, a unique problem in the mining industry.

Since it is necessary for the coal miner to hear and understand these two principal types of acoustic signals, speech and roof talk, the Pennsylvania State University, under a research grant by the Bureau of Mines,[2] undertook the task to determine the ability of miners to detect roof talk and speech signals with and without standard ear protectors in a simulated mine environment.

According to their results, ear protection should be worn by the miner only when sound levels exceed 90 dbA. To this end, research at the Bureau's Pittsburgh Mining and Safety Research Center (PMSRC) has resulted in the development of a discriminating earmuff that attenuates sound levels in excess of 90 dbA.

SPEECH AND WARNING SIGNAL DISCRIMINATION

It is necessary for coal miners to be able to hear and understand two principal types of acoustic signals when they are at work. These are (1) the speech of their coworkers and (2) sounds generated by stress release in the mine roof that are indicative of imminent roof fall--roof talk signals. A series of tests were developed at the Pennsylvania State University to determine the ability of subjects to detect speech and roof talk signals both with and without standard ear protectors in simulated coal mine situations.

Subjects were placed in an acoustic test room as shown in figure 3. The tests administered were as follows:

a. Speech at 70 db L_p in quiet;

b. speech at 60 db L_p in quiet;

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[2] Pennsylvanis State University. Aspects of Noise Generation and Hearing Protection in Underground Coal Mines. BuMines Open File Rept. 19-73, Nov. 20, 1972, 158 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Washington, D.C.; and from National Technical Information Service, Springfield, Va., PB 219 087.

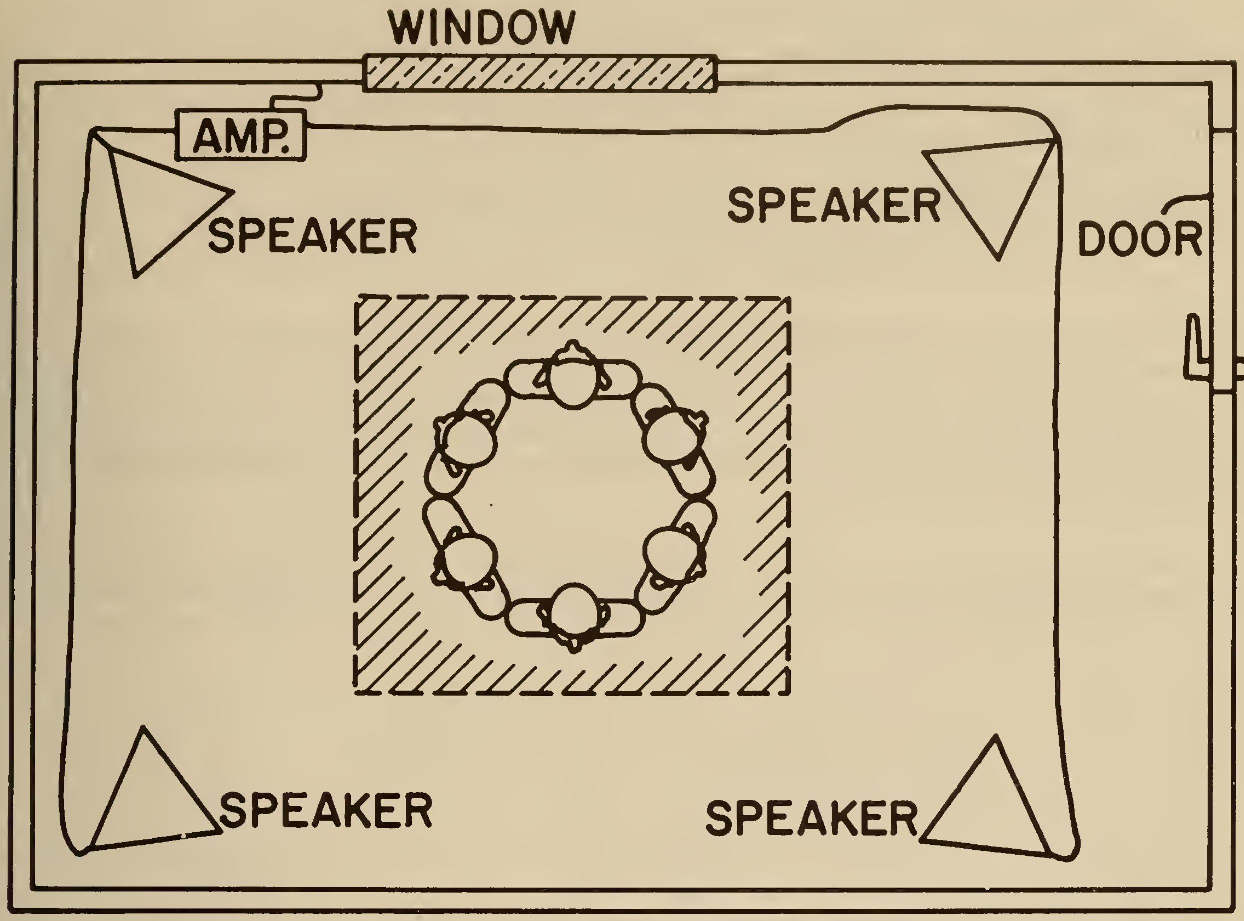


FIGURE 3. - Arrangement of examining room.

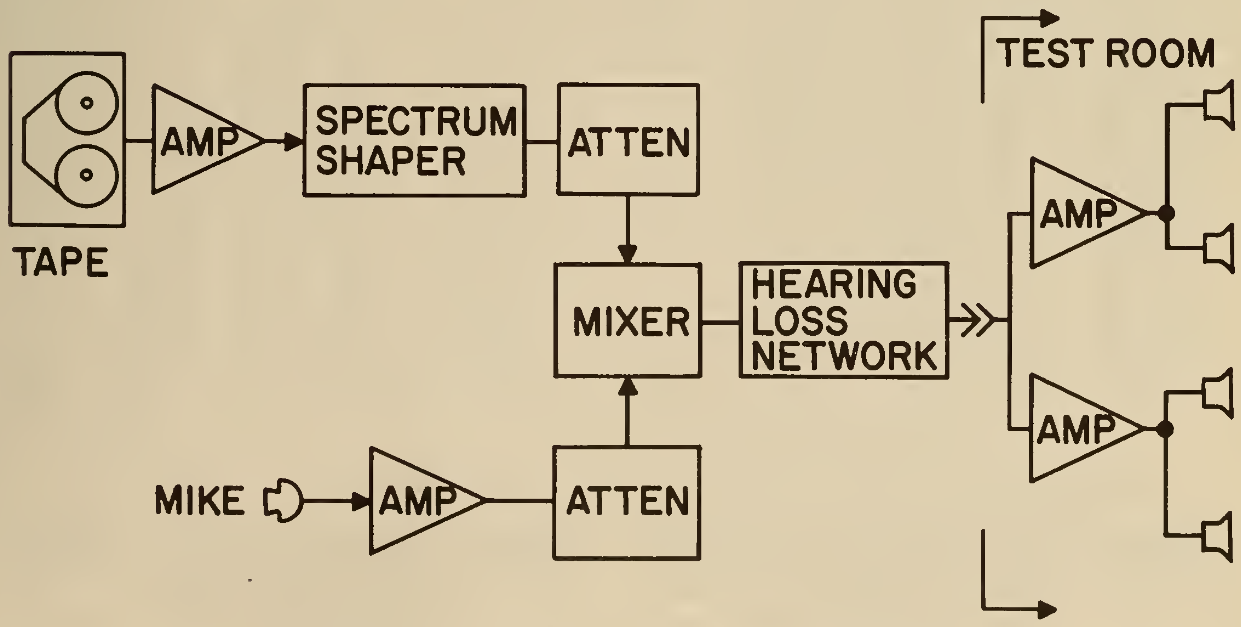


FIGURE 4. - Signal discrimination test instrumentation.

c. speech at 70 db L_p in noise of 70 db L_p;

d. speech at 70 db L_p in noise of 80 db L_p;

e. speech at 70 db L_p in noise of 90 db L_p.

Roof talk listening was done under three conditions:

a. Roof talk at 70 db median peak L_p in noise of 80 db L_p;

b. roof talk at 70 db median peak L_p in noise of 90 db L_p;

c. roof talk at 70 db median peak L_p in noise of 100 db L_p.

Noise levels in all cases were selected to replicate typical listening situations found in coal mines.

Subjects were tested in each of the aforementioned listening conditions with and without ear protectors. Discrimination tests for speech were based on the identification of a word list read to them under the different test

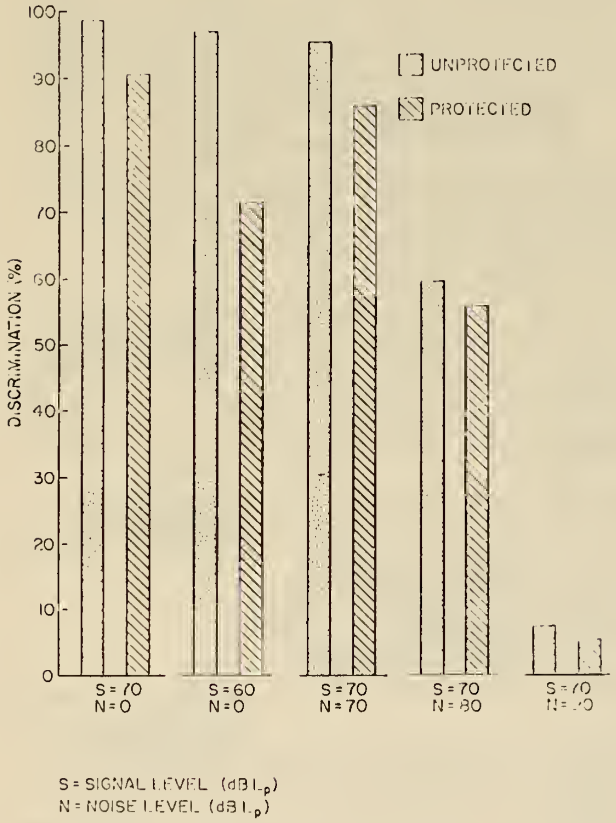


FIGURE 5. - Normal hearing subjects' mean discrimination of speech signals with and without ear protectors.

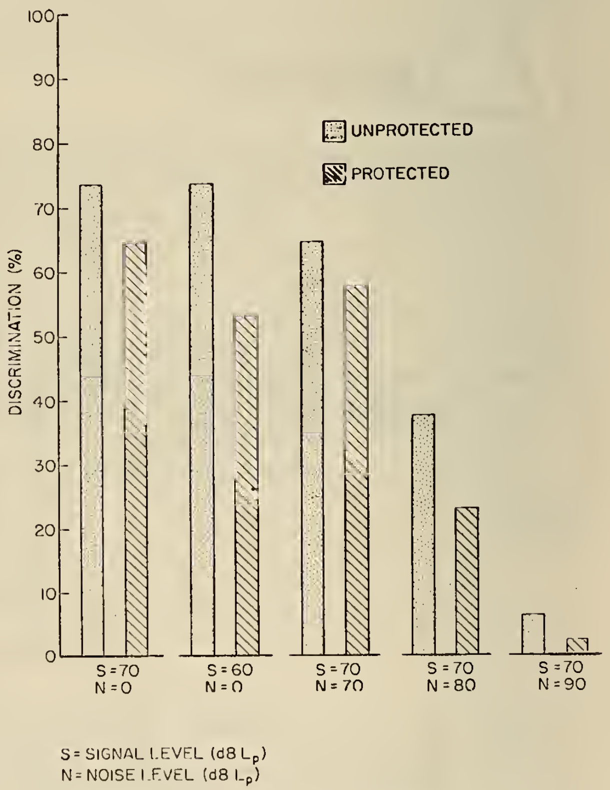
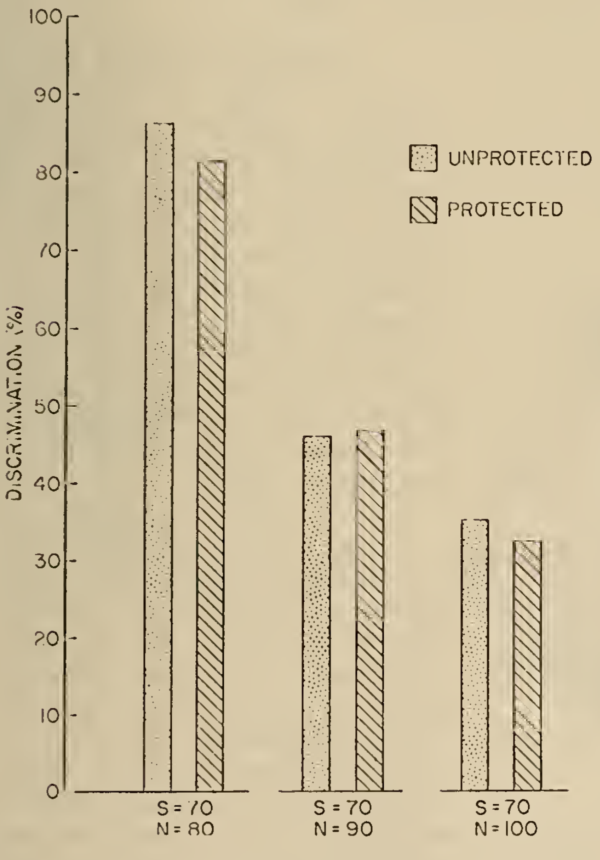


FIGURE 6. - Simulated hearing loss subjects' mean discrimination of speech signals with and without ear protectors.

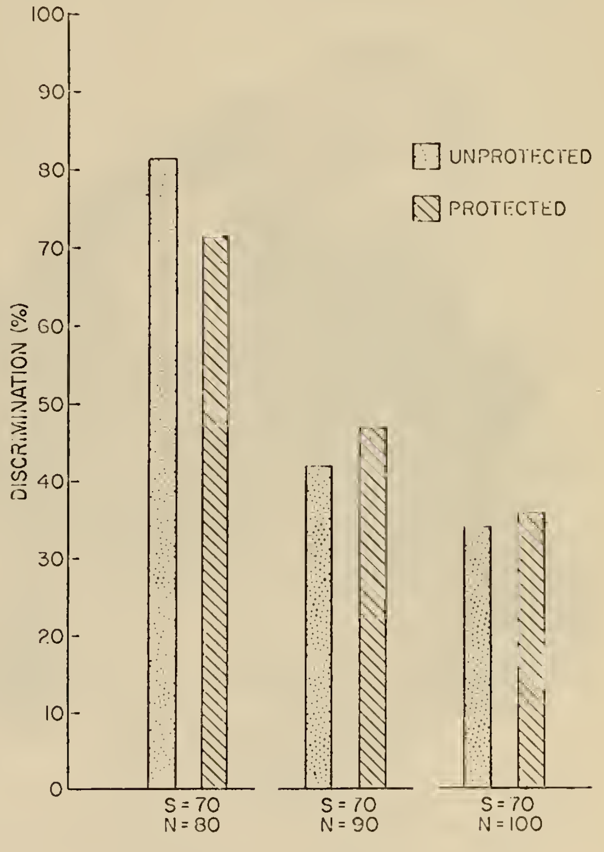
conditions. The discrimination test for roof talk was the detection or absence of a roof talk under the different test conditions. Discrimation tests for both speech and roof talk signals were performed with normal hearing subjects and with subjects with simulated hearing losses. Each subject was tested conventionally and then all tests were repeated using a hearing loss simulated filter. This device filters signals so as to duplicate the frequency response aspects of the hearing losses seen in coal miners aged 50 to 59 years as shown in figure 1. The instrumentation used for this testing is shown in figure 4.

Mean discrimination scores are reported in figures 5-8. These findings confirm that the use of ear protectors in noise of 90 db L_p and above does not further impede discrimination of speech of roof talk signals. It is also apparent that the use of ear protectors in low level noise environment results in reduced auditory discrimination of both speech and roof talk signals.



S = SIGNAL LEVEL (dB L_p)
N = NOISE LEVEL (dB L_p)

FIGURE 7. - Normal hearing subjects' mean discrimination of roof talk signals with and without ear protectors.



S = SIGNAL LEVEL (dB L_p)
N = NOISE LEVEL (dB L_p)

FIGURE 8. - Simulated hearing loss subjects' mean discrimination of roof talk signals with and without ear protectors.

In general, then, the use of ear protectors is suggested only when noise levels exceed the 90-dbA limit. This practice will protect the hearing of coal miners without impeding their ability to hear and recognize speech and roof talk signals. Clearly, in the typical coal mine work environment, this would necessitate an almost continual process of putting on and taking off ear protectors and could prove costly in terms of working time and efficiency. Therefore, it would be desirable to use an ear protector device that automatically provides the requisite attenuation only when noise exposure limits are exceeded.

DISCRIMINATION EARMUFF

As a result of the Pennsylvania State University investigation, it has been determined that an ear protector is needed that can be continuously worn by the miner. This earmuff would allow his protection when noise levels exceed 90 dbA, as a standard earmuff would, and yet enable him to hear normally below such levels, as the removal of the earmuff would.

FIGURE 9. - Discriminating earmuff.

Research at PMSRC has resulted in the development of such a device in the discriminating earmuff (fig. 9). The transfer function of input sound pressure versus the perceived pressure is shown in figure 10. The transfer function was found by applying an electrical signal of 1 kHz to the microphone input and measuring the acoustic output on an artificial head.

The device performs in two modes of operation. For input sound pressures less than or equal to 83 db, the user hears at normal levels; that is, if he is exposed to a sound pressure of 83 db or less he hears 83 db or less. For inputs in excess of 83 db, the second mode of operation begins. The sound being perceived by the user is now progressively attenuated as the input level is increased. A recognizable difference still exists between two adjacent sound levels, enabling the user to

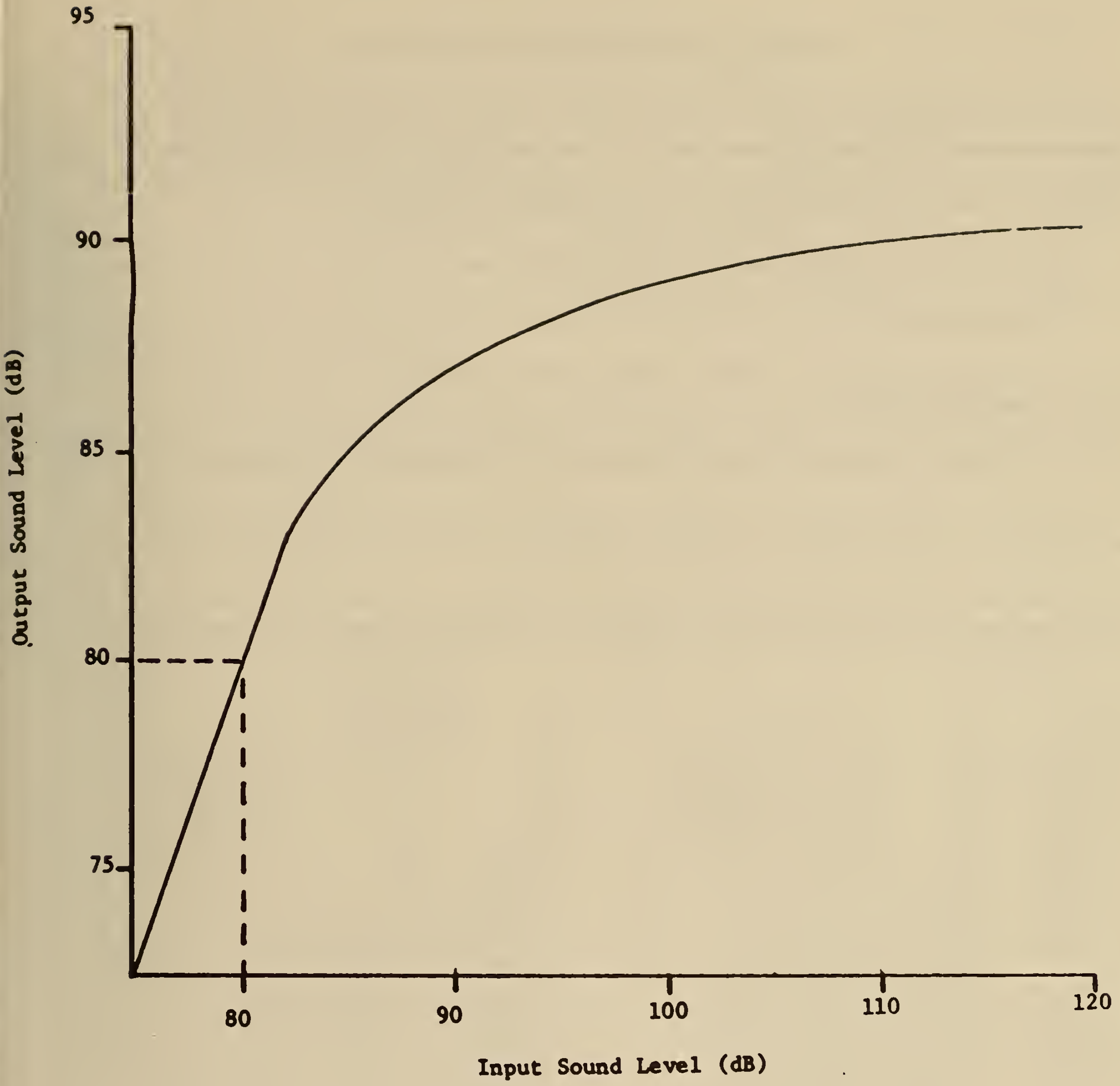


FIGURE 10. - Curve of input sound level versus perceived level.

differentiate between the two levels. For simplicity the threshold circuitry was not designed to be frequency sensitive, and so the actual dbA threshold level depends on the spectrum of the input noise. The upper limit of sound pressure level being transmitted to the user at a sound pressure level of 120 dbA is 90 dbA. Beyond this level the natural transmission of acoustic energy of the earmuff will be greater than that of the electronics.

Discriminating Earmuff Evaluation

It was desired to perform an extensive series of signal discrimination tests to evaluate the applicability of the discriminating earmuffs to the coal mine environment. Again these tests were performed at the Pennsylvania State University, and the procedures used were very similar to those used in the standard earmuff discrimination tests mentioned earlier.

Ear protector conditions in these tests were--

1. Unprotected.

2. Wearing discriminating earmuff with electronics turned off--simulating a standard earmuff.

3. Wearing discriminating earmuff with electronics turned on.

Again the tests were performed for normal hearing and with a simulated hearing loss. The results of these tests are shown in figures 11-14.

Figures 11-12 show an improvement in speech discrimination at all levels when wearing the discriminating earmuff in comparison with the standard

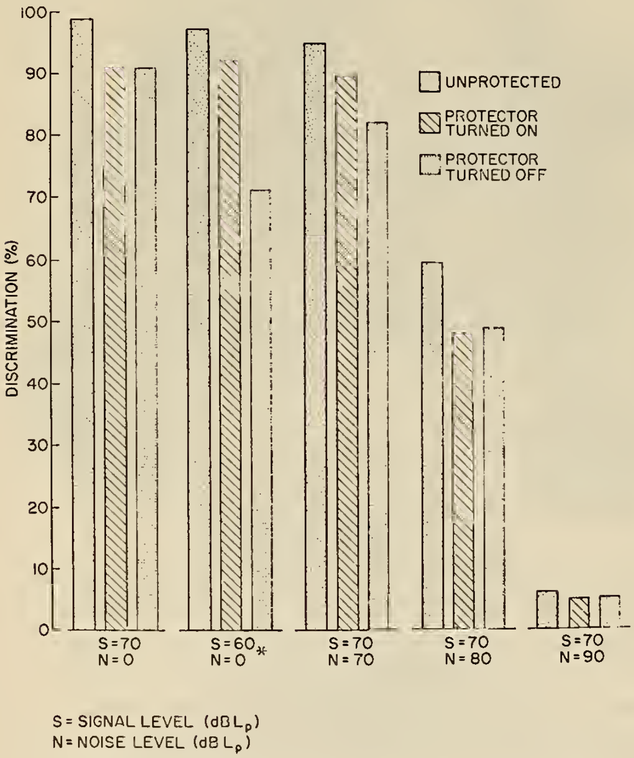


FIGURE 11. - Evaluation of electronic ear protector by normal hearing subjects listening to speech signals.

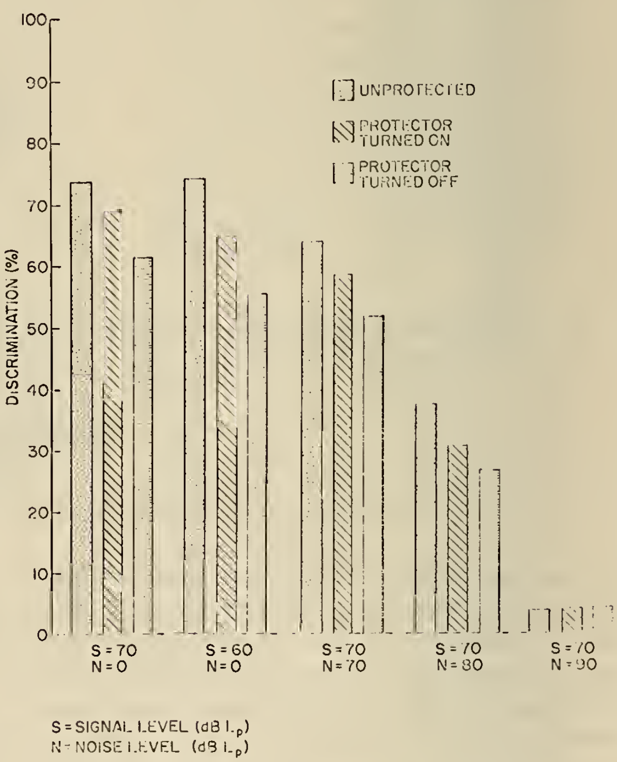


FIGURE 12. - Evaluation of electronic ear protector by subjects with simulated hearing loss listening to speech signals.

earmuff. A significant improvement can be seen in figure 11 for a signal level (S) of 60 db L_p and a noise level (N) of zero db L_p.

The major complaint by the miners in wearing standard earmuffs is that they say they cannot hear well enough and the sounds they hear are unnatural. By not hearing well enough, the miners mean that many low-level sounds such as background noises become completely muffled or sound unnatural due to the unequal frequency attenuation of the standard earmuff. If a signal is low to begin with and is further attenuated, it may become completely inaudible. Also, with the different attenuation of the various frequencies, the signal heard while wearing the standard earmuff might sound completely different from that heard with no protection.

In contrast, the discriminating earmuff amplifies all frequencies equally giving rise to (1) good detection of a low level signal and (2) natural hearing of the sound being generated. Referring back to the particular test for

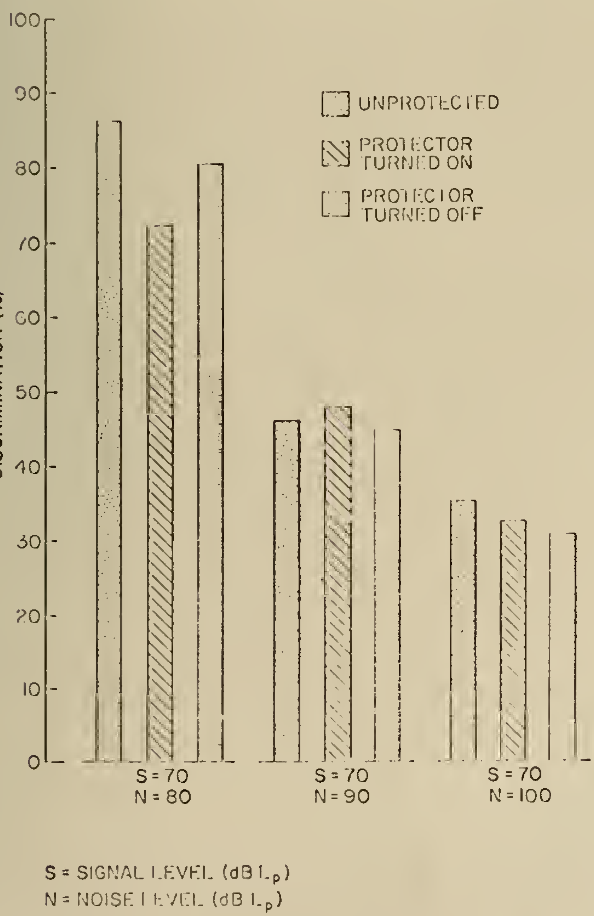


FIGURE 13. - Evaluation of electronic ear protector by normal hearing subjects listening to roof talk signals.

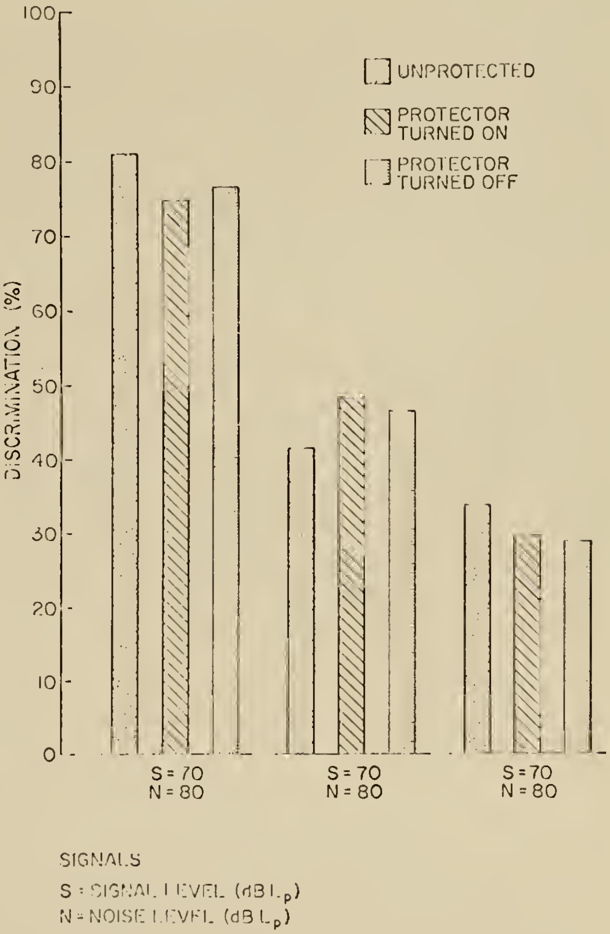


FIGURE 14. - Evaluation of electronic ear protector by subjects with simulated hearing loss listening to roof talk signals.

S = 60 db and N = zero, we might look upon this as testing for background discrimination. The significant improvement when wearing the discriminating earmuff represents an important outcome since this gives an improvement in background detection and identification that might consist of speech or machinery noise, both of which are important to the miner's total perception of his environment.

Figures 13-14 show that roof talk discrimination is improved in all cases except for the low noise test.

An important note should be made here; the bar graphs represent mean discrimination scores; that is, eight scores were averaged. It was later found that two of the eight discriminating headsets had grossly poor discrimination scores, yet their results were averaged in with the other six. It is possible that there existed a fault in the two headsets, in either the electronics, acoustics, or mechanical structure. If the fault were corrected, it is expected that the discrimination scores for the discriminating earmuff would improve significantly.

In conclusion, the results demonstrate that the discriminating earmuff improves the subject's hearing and understanding of the two principal types of acoustic signals below 90 dbA of noise yet at the same time protects him from harmful exposures when the noise exceeds 90 dbA. Continuing research is being done to improve the degree of discrimination since the ultimate goal is that the scores of the discriminating earmuff equal those of no protection at lower noise levels.

Discriminating Earmuff Field Tests

Since the conception of the device was to help the miner, the discriminating earmuff had to be taken out of the labs to give the miner an opportunity to give it a working test. This field test was performed through the U.S. Steel Corp. in cooperation with several of their coal mines. The units were distributed to miners working in various noise areas of the mine. The results received from these tests were both encouraging and constructive. The miners noted good protection from high noise sources and were pleased to be able to easily communicate with their coworkers at low noise environments. They also pointed out the need to make the device more durable for actual mine use.

Since in the final analysis an item must not only be acceptable but wanted by the miner, the discriminating earmuff is felt to be the first step in that direction.

CONCLUSION

The ultimate solution of the mine noise problem is the removal or damping of the sources, which cause not only a health hazard but a safety hazard as well. Removal or damping of the sources, though ideally the best, may be one of the future if it exists at all. It is presently felt that a device, the discriminating earmuff, has been made available to the mines that will bridge the gap between the miner's concurrent need for protection and for a natural perception of his working environment.

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Building Stoppings in Mines With Large Openings

UNITED STATES DEPARTMENT OF THE INTERIOR

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Building Stoppings in Mines With Large Openings

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BUILDING STOPPINGS IN MINES WITH LARGE OPENINGS

by

Edward D. Thimans[1] and Fred N. Kissell[2]

ABSTRACT

The Bureau of Mines conducted a state-of-the-art study of techniques currently employed to close large openings in underground mines. A large opening was considered to be any opening over 10 feet high and having a cross section of at least 200 square feet.

Five salt mines and one limestone mine were visited to observe various methods of sealing large openings. Because of the variations in conditions from mine to mine, no definite conclusions could be drawn as to which is the best method. In mines where waste material is available, stoppings built by piling waste material are efficient and economical. Where waste material is not available properly constructed brattice cloth stoppings are superior to those built from wood, concrete block, or urethane foams.

INTRODUCTION

Most of the mines with large openings in the United States today are salt and limestone mines. Some potash and trona mines also have moderately large openings. Moreover, it is expected that in the near future numerous underground oil shale mines will be developed in the oil shale regions of Colorado, Utah, and Wyoming. These mines will also have large openings ranging up to 2,000 or 3,000 square feet in area.

In general, mines having large openings move considerable volumes of air through the mine for ventilation purposes. However, because of the large cross sections of the airways, the flowrates are often quite low, sometimes less than 100 fpm, making these ventilation systems less efficient than those in mines with small airways. In addition, poorly constructed stoppings can result in substantial losses of intake air before it reaches the working face. If auxiliary fans are located in an insufficient air base, they can result in recirculation of return air into intake airways.

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[2]Physical research scientist.

In mines with large openings, as in all mining operations, the budget and the size of the work force are limiting factors. They can have a significant influence on the manner in which stoppings are constructed. The location of the stoppings and whether they are to be temporary or permanent are important factors. If stoppings are constructed in the vicinity of the working face, they will be exposed to blasting pressures and flying debris. Stoppings in airways that carry mine traffic must be constructed to allow for the movement of mine equipment. Stoppings that are needed for only a short time can be built more rapidly and cheaply than permanent ones.

To obtain information on the current methods of closing large openings, several mines containing such openings were visited. The various procedures for closing large openings used at these mines were studied and evaluated.

CLOSING OPENINGS WITH WASTE MATERIALS

Many hardrock mines have large quantities of mined waste materials that must be disposed of either in the mine or outside in waste piles. In some mines this waste material is being used to close up large openings. Stoppings can be built of waste material in several different ways.

One method is to pile heavy burlap sacks filled with fine waste material to form a stopping across an opening in much the same way as a levee is built to prevent flooding. Because of its high density, this type of stopping is airtight and fairly stable, even against blast forces. It also has the advantage that the waste bags can adjust and compress to allow for roof sag without weakening the stopping. On the other hand, construction of this type of stopping requires a considerable number of man-hours, especially in high openings where the difficulty of piling the bags increases with stopping height. Another disadvantage of this type of stopping is that it closes the roadway permanently to future mine traffic. This may or may not be a problem. In the case of a mine fire, these stoppings could collapse if the burlap sacks catch fire.

In some mines where large quantities of waste material are available, a common practice is simply to close large openings by dumping the waste material in the opening and bulldozing it to the roof with a bulldozer or front-end loader. This type of stopping forms an extremely efficient, stable air barrier. Its construction is fairly time consuming because of the hauling and plowing required, but otherwise the wastes would have to be hauled away for disposal. The main drawbacks of this procedure are the difficulty of plowing the wastes completely to the roof, especially in high airways, and the gaps that eventually develop between the roof and the waste pile due to settling. Like the wastebag stoppings, these stoppings permanently prohibit mine traffic.

In an attempt to eliminate these problems, some mines have tried variations of this procedure. The waste material is pushed to within several feet of the roof and the remaining gap between the roof and the waste pile is closed either with bags of waste material or with brattice cloth (fig. 1). Because piling bags of waste is both difficult and time consuming, and gaps continue to form due to settling, hanging short pieces of brattice cloth

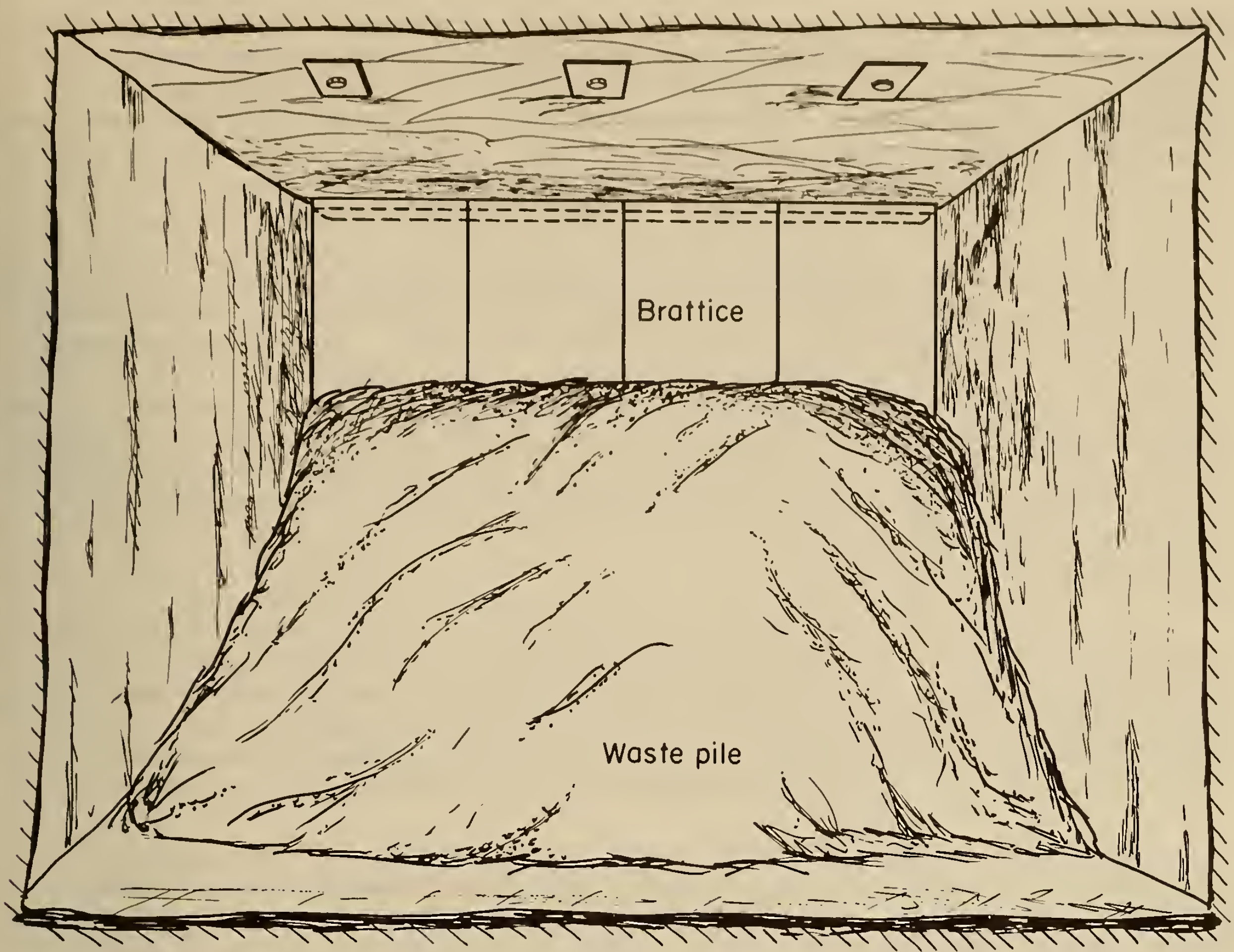

FIGURE 1. - Stopping made from waste material with brattice cloth hung to close upper portion of opening.

appears to be preferable. A trench 1 to 2 feet deep is dug along the top of the waste pile, and short lengths of brattice cloth are hung from the roof, extended into the trench, and secured by filling the trench with fine wastes. As the waste pile settles the brattice cloth slides up through the wastes and prevents a gap between the roof and waste pile. The major objection to using brattice cloth in this way is that the cloth may be damaged by blasting if the stopping is near the working face.

All of the stoppings built by piling waste materials are fairly fire resistant.

URETHANE-FOAM SEALED STOPPINGS

In two of the mines visited, stoppings had been constructed by hanging several layers of chicken wire across the opening and coating it with a heavy layer of urethane foam. Stoppings constructed in this manner proved to have drawbacks far outweighing their benefits. As air barriers these stoppings are

extremely efficient, but they are very time consuming and expensive to erect, they are too light to withstand blasting, and they permanently prevent mine traffic. In addition, the flammability problem associated with the use of urethane foam may restrict its use in many mines, although some urethane foams now contain fire-retardant chemicals.

STOPPINGS FROM CONCRETE BLOCKS OR WOOD

Concrete block stoppings have been employed successfully in several mines with large openings where they have proved to be effective air seals. Concrete block stoppings are also highly fire resistant. However, construction of this type of stopping should be avoided in mines where there is a gradual sagging of the roof. Salt mines are an example of this type of mine. In such mines the concrete block stoppings will be destroyed as a result of crushing. Other negative factors are the high costs of construction and the possibility of severe blast damage if the stoppings are too close to the working face. Concrete block stoppings should be constructed far enough from the face to avoid large blast pressures.

Various ways of constructing wood stoppings in large openings have been tried, but none of them have proved successful near the working face where they incur extensive blast damage. Wooden stoppings are generally constructed by building a frame with two by fours and covering it with plywood or some other sheeting. Such stoppings are fairly time consuming to construct and do not usually form a good airtight seal with the walls and roof.

One mine attempted to protect wood stoppings against blast damage by attaching the stoppings to roof bolts projecting several inches from the roof and allowing the stoppings to float a few inches off the mine floor. It was hoped that the stoppings would swing back on the roof bolts to relieve the blast force, but they were still heavily damaged by blasting.

A second procedure that was attempted was to build swinging doors in the stoppings to relieve the blast pressures. Various sizes and types of doors were tried, but damage due to blasting continued to be substantial, because the shock wave velocities from the blasts were too high for a swinging stopping or a door to offer relief.

Wood stoppings also offer little resistance to fire.

CLOSING LARGE OPENINGS WITH BRATTICE CLOTH

Methods of hanging brattice cloth to close large openings and the types of brattice cloth used for this purpose vary considerably from mine to mine. Most of the damage to stoppings built with brattice cloth is caused by blasting or moving equipment. Blasting damage can vary from complete destruction of the stopping by shock waves to holes caused by flying debris. Moving equipment generally damages the brattice cloth by snagging as it moves through the stopping.

Most of the mines visited had at one time or another used jute brattice. Where the humidity was high, the jute cloth proved unsatisfactory. Both the additional weight due to the absorbed moisture and the gradual decay which occurred to the moist jute made the useful life of stoppings constructed with this material very limited. In mines with low humidity the jute brattice appears as good as any other material. One of the mines was using jute brattice coated with plastic on one side, which made it stronger, less absorbent, and more airtight than plain jute cloth. Although it was not observed to be in use, jute brattice with plastic coating on both sides is also available commercially and would eliminate the problem of moisture absorption.

The most common type of brattice material employed in large opening mines is plastic brattice which can be purchased in various thicknesses and strengths. Plastic brattice is generally preferred because it is airtight, does not absorb moisture, and slides easily over moving mine equipment.

In all of the mines visited in this study, the brattice materials used were in conformity with the ASTM, E-162 flame spread specifications. They all had a flame spread index of less than 25.

All types of brattice material can be easily damaged by blasting and by moving mine equipment. This, coupled with the need for stoppings which act as efficient air barriers, points to the importance of having workable methods for building and repairing brattice cloth stoppings.

One of the more frequently employed methods of hanging brattice cloth in large opening mines is to hang the cloth from a wire cable attached to the roof and ribs of the opening. Several variations of this method were observed. In one mine, the wire cable was attached to the rib by means of a turnbuckle located a few feet from the mine floor. The cable was then run up along the rib, across the roof, and down the other rib where it was attached to a second turnbuckle. The cable was fastened to the roof and ribs by clamps or roof bolts driven into the rock. The brattice cloth, which generally comes in widths of from 7 to 9 feet, was lapped about 6 inches over the cable and clamped to the cable at the roof and ribs about every 6 inches with small metal C-rings that were squeezed shut around the cable (fig. 2). The individual widths of brattice cloth that were hung side by side were overlapped 1 to 2 feet to cut down on air leakage. An extra 2 or 3 feet of brattice were allowed at the floor for the same purpose. The brattice cloth used in constructing these stoppings was purchased in long rolls, and the individual vertical panels were cut to the desired length.

Another mine used a similar technique, except that the brattice cloth was purchased in precut lengths to exactly match the openings and grommets were attached along the top of each brattice panel. The wire cable can be passed through the grommets before being raised and attached to the roof and ribs, or the cable can be hung first and the brattice cloth attached to the cable by running plastic fasteners through the grommets and around the cable. All of these methods of hanging brattice result in stoppings that are good air seals if they are properly maintained. They also offer the advantage of allowing

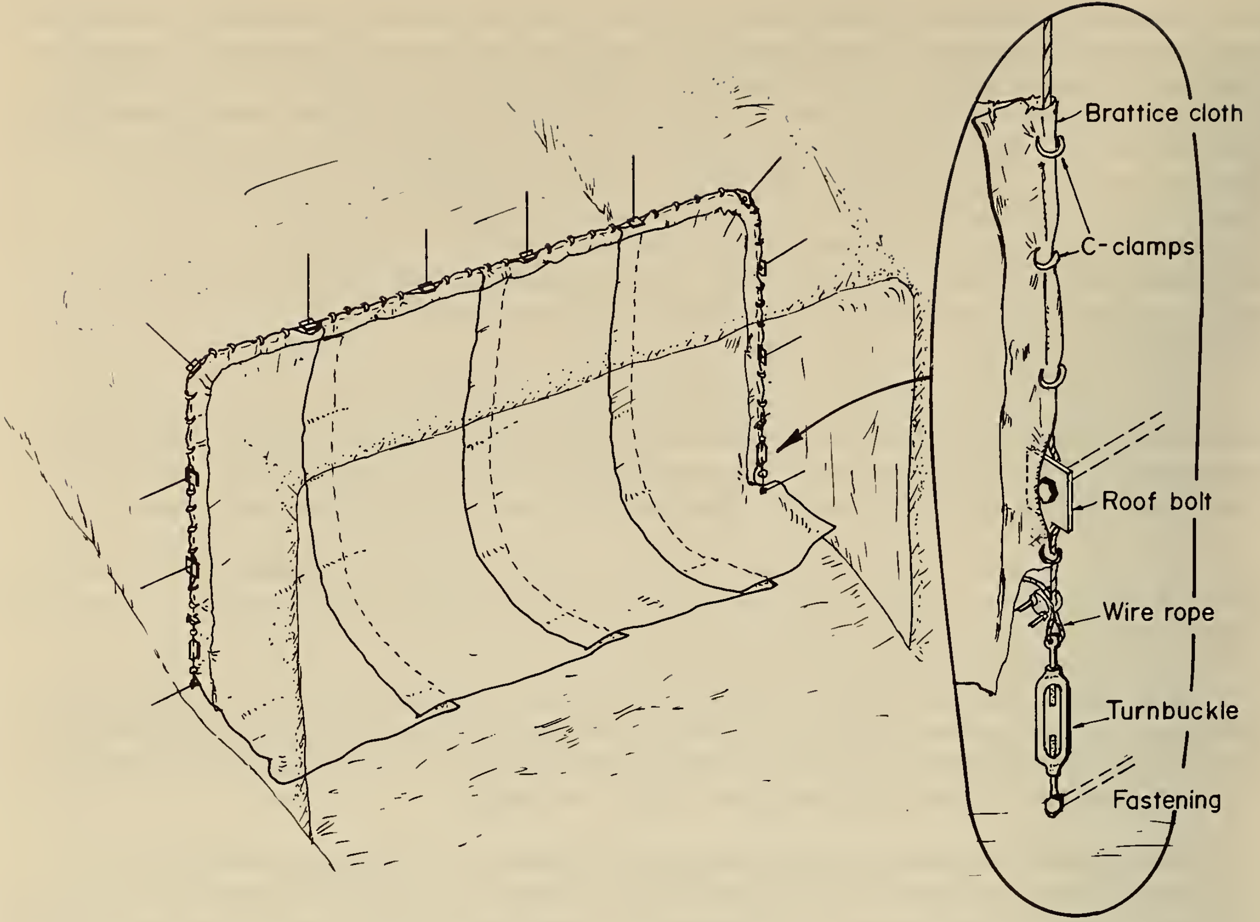

FIGURE 2. - Brattice cloth stopping hung from cable with C-rings.

mine traffic to pass through them if care is taken not to snag the brattice material. Their big drawback is that they can be easily torn at the points of attachment by blasting.

In two of the mines visited, some brattice cloth was attached to the roof and ribs with a spad gun at intervals of about 1 foot. This is not a recommended technique because the brattice can easily be torn where the spads are driven through it. In one area where jute brattice was hung in this manner, the brattice tore away from the spads after increasing in weight as a result of moisture absorption. However, if a short-term temporary stopping is needed, then this method of hanging brattice cloth might be acceptable.

Several mines had tried purchasing brattice materials in single precut sections, sewn to fit the openings. In some cases these premade sections were as much as 40 feet high by 60 feet wide. These sections were purchased with grommets along the top edge by which a section could be attached to a wire cable as described in one of the previously discussed methods. Such stoppings are more severely damaged by blasting than those hung as a series of smaller vertical panels. The premade curtains are also substantially more expensive

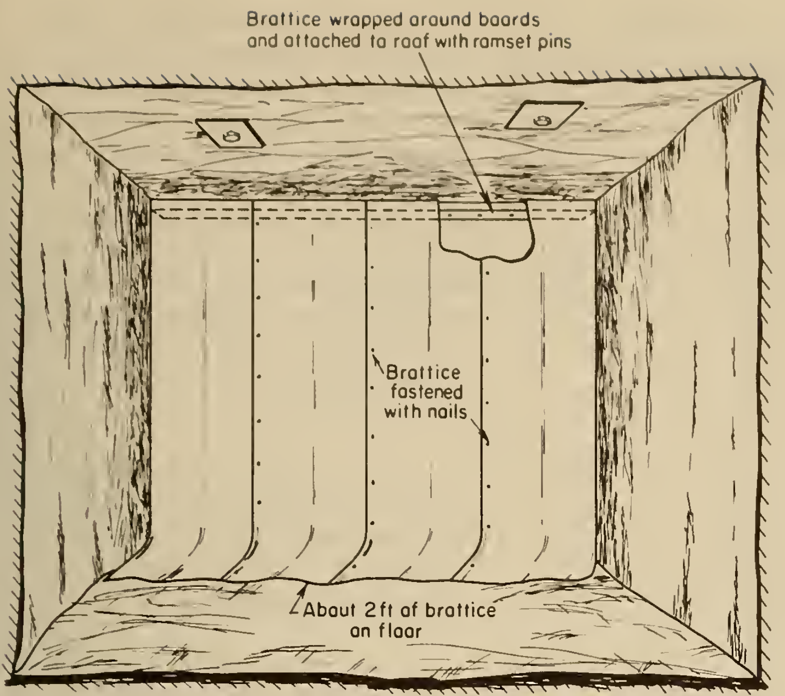

FIGURE 3. - Brattice cloth stopping hung with powder-actuated gun.

than buying rolls of brattice material and cutting smaller panels to the required lengths.

Of all the brattice hanging techniques observed, the following is considered to be the most effective. The brattice cloth, either jute, plastic-coated jute, or plastic, is purchased in long rolls, 8 feet wide. A length is cut from the roll about 4 feet longer than the height of the opening to be closed. One end of this panel is then wrapped a few times around a 1- by 3-inch board, 8 feet long. This board is attached to the roof with pins fired by a powder-actuated gun and spaced about 18 inches apart (figs. 3 and 4). Hanging the brattice in this way leaves about 2 feet of excess material at the floor for an improved air seal. The individual 8-foot-wide panels overlap from 6 to 12 inches and are pinned together with nails. The big advantage to this form of stopping is that it does not tear away at the roof because the stress on the material at the roof is equally distributed, whereas if the connections are made with spads, grommets, or C-rings, the tears begin at these locations. The nail pins connecting the individual panels cut down on air leakage, but will be torn out to relieve blast pressure without any serious damage to the stopping. If traffic is to move through the stopping, the lower part of one panel is not pinned to the adjacent panels so that it can slide over the moving vehicle.

COST CONSIDERATIONS

A cost comparison of the different methods of closing large mine openings is difficult because of variations from mine to mine both in available materials and in labor costs. However, it is possible to draw some generalized economic conclusions from the data obtained in this study.

1. If waste material is available and if no problems are created by permanently closing certain openings to mine traffic, then the most economical method of closing a large opening is by using waste material in one of the techniques discussed. The labor costs associated are high, but they are partially amortized by the resulting disposal of the waste material and increased utilization of available air.

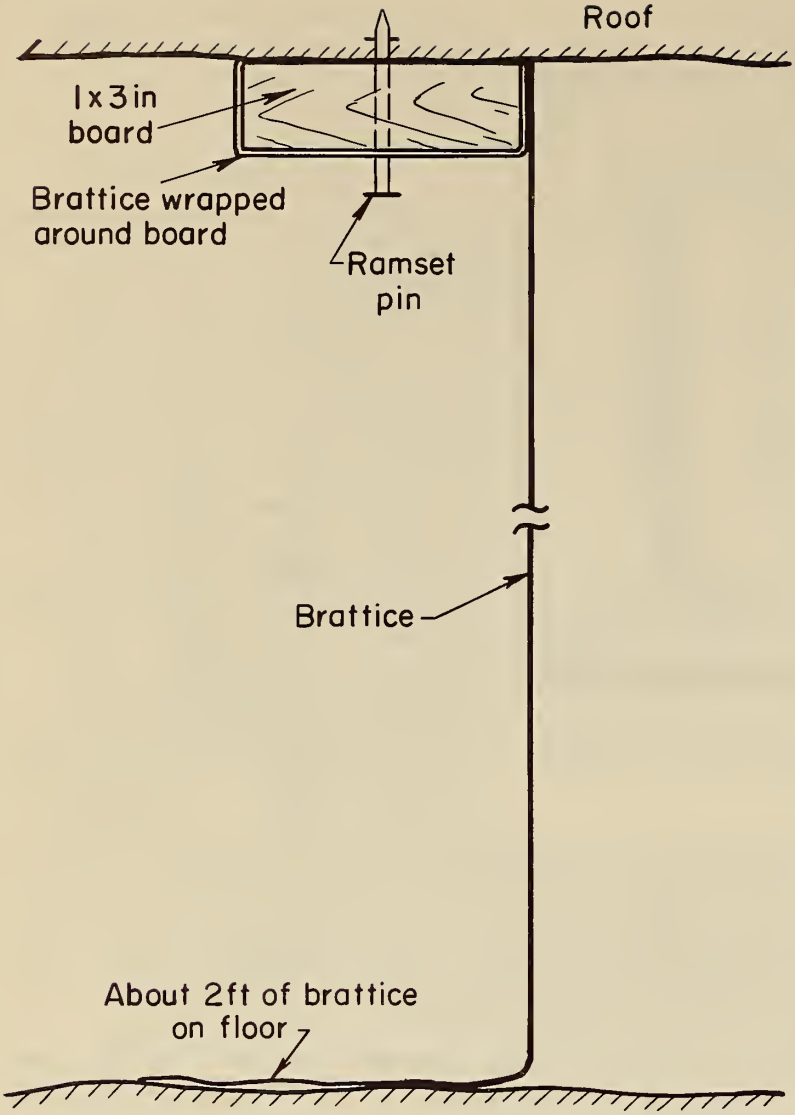

FIGURE 4. - Brattice cloth wrapped around board and attached to mine roof with powder-actuated gun.

2. Foam-covered stoppings are generally very expensive because they use not only foam but backup materials such as chicken wire over which the foam is sprayed. In some cases it may be advisable to use foam around the edges of a stopping to improve the air seal, but this would depend upon individual circumstances.

3. Concrete block and wood stoppings are expensive to construct as a result of the high costs of both material and labor.

4. The material cost of available brattice materials varies substantially. If 14-ounce material is considered, the cost ranges from about \$0.50/yd^2 for jute brattice to 1.70/yd^2 for plastic brattice, with jute covered with plastic on one side running about \$0.90/yd^2.

5. In the case of brattice cloth stoppings, the labor costs also vary considerably with the method of construction. Hanging the brattice with a spad gun is relatively inexpensive, but is not the best in terms of stopping durability. Wrapping the brattice around a board and attaching the board to the mine roof with a powder-actuated gun is not only the best technique for building a brattice stopping but also requires less labor than most of the other brattice-hanging techniques, and the increased durability of the resulting stopping has obvious financial benefits.

CONCLUSIONS

The results of this study are summarized in table 1. Each of the methods for closing large openings that were investigated is rated on several key points and its cost is estimated. The estimates include labor and material

costs, and are based on a 30- by 30-foot opening. It should be noted that the costs of techniques involving piling waste material are partially amortized by the cost of the labor that would be required to remove waste material if it were not utilized to build stoppings. With this in mind, the table shows that piling waste material is a good method of closing a large opening.

It will also be seen that if a brattice cloth stopping is to be constructed, the most efficient and economical method is to wrap the brattice around a board, attach it to the roof with a powder-actuated gun, and pin the separate panels together with nails.

TABLE 1. - Summary of findings

Method	Effectiveness as air seal	Ability to withstand blasting	Ability to withstand roof sag	Fire resistivity	Effect on mine traffic	Estimated total cost to close 30- X 30-foot openings
Pile up bags of waste material.	Very good....	Very good.	Very good.	Fair.......	Does not permit.	$1,000
Plow up waste material.	.....do......	...do.....	...do.....	Very good..	...do.......	1,000
Urethane-foam-sealed stopping.	.....do......	Poor......	Poor......	Depends on type of foam.	...do.......	1,800
Concrete block stoppings.	.....do......	Good......	...do.....	Very good..	...do.......	1,200
Wood stoppings......	Fair.........	Poor......	...do.....	Poor.......	...do.......	1,000
Hang brattice from wire cable.	Good.........	Fair......	Good......	Fair.......	No effect...	With 14-oz jute--$400. With 14-oz plastic--$500.
Hang brattice with spads.	.....do......	Poor......	...do.....	...do......	...do.......	With 14-oz jute--$300. With 14-oz plastic--$400.
Wrap brattice around board and attach to roof with powder-actuated gun.	.....do......	Good......	...do.....	...do......	...do.......	With 14-oz jute--$300. With 14-oz plastic--$400.

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